6. Biological Resources

Overview

Each of the plant and animal populations within the Puget Sound basin contribute to the biodiversity and ecosystem function in the region. Many species are also important economic and cultural resources. Plants and animals have always faced environmental stressors associated with predators, competition and pathogens. These species and the habitats upon which they rely have continually faced natural disturbances related to climatic or geologic events. However, the dramatic increase in human population and the introduction of industrial activities in the last century have brought intense pressure on many species through direct harvesting, alteration and contamination of food webs and loss of habitat. The introduction of invasive exotic species has also increased competitive pressures on many native species.

Most research has focused on relatively few economically or recreationally important species. Consequently, little is known about the majority of Puget Sound plant and animal species. Nevertheless, scientists have documented many cases of sharp declines in abundance in a diverse set of species that include fish, marine birds and a marine mammal (i.e., the southern resident orca population). Conversely there are examples of increasing abundance that confound a simple interpretation of a system in decline (e.g. harbor seal, merganser, bald eagle) and other species whose abundances reflect natural processes and events more so than human influences (e.g. kelp bed extent).

Efforts at a variety of organizational levels are directed at protecting biological resources. These include land-use planning efforts at the local level, management of fisheries and game species by tribes and the state, and direct protection by federal legislation such as the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA).

Photo credit clockwise from upper left: Wayne A. Palsson, Joseph Evenson, Randy Shuman and Brian Walsh.

A number of species in the Puget Sound area have received protection under ESA, most recently, several salmonid populations in 1999. Others have recently been studied for potential protection, for example the orca whale (*Orcinus orca*). Salmon species currently listed as threatened under ESA include Puget Sound chinook salmon (*Oncorhynchus tshawytscha*) and Hood Canal summer-run chum salmon (*O. keta*). coho salmon (*O. kisutch*) is currently a candidate species for listing. A number of marine fish species were also reviewed for ESA protection, but six were declined and Pacific whiting (hake) was retained as a candidate species. Protection of these species under ESA falls under the jurisdiction of the National Marine Fisheries Service (NMFS). The recovery of the bald eagle over large areas of the U.S., including Puget Sound, is considered a major success of the ESA—in this case under the jurisdiction of the U.S. Fish and Wildlife Service.

Marine reserves are another management tool available to protect biological resources from human activity. Marine reserves are currently attracting increasing interest and scientific inquiry to understand their effectiveness and design parameters (Palsson 2002; Eisenhardt 2002; Salomon 2002).

This chapter presents monitoring results from the Puget Sound Ambient Monitoring Program (PSAMP) and related efforts that cover a wide range of biological resources from primary producers at the bottom of food webs (phytoplankton and aquatic vegetation) through marine macro-invertebrates, fish, birds and marine mammals at intermediate trophic levels, to organisms at the top of their respective food webs, such as the orca whale and bald eagle. Some of the new findings and accomplishments highlighted in this chapter are summarized in the following list.

Vegetation, Phytoplankton and Macro-Invertebrates

- Scientists at the Washington State Department of Natural Resources completed a statewide inventory of the shoreline called the ShoreZone Inventory in 2000. The inventory characterizes shoreline geomorphology, vegetation, and anthropogenic development along the 3000 miles of saltwater shoreline in Washington State.
- In 2000, the Department of Natural Resources sampled eelgrass beds at 67 sites throughout Puget Sound as part of a new Submerged Vegetation Monitoring Program. This study provides the first estimate of the amount of eelgrass in Puget Sound, and other information on eelgrass bed characteristics. It also serves as a baseline for a long-term monitoring program.
- Kelp canopy area in the Strait of Juan de Fuca increased in both 1999 and 2000 following a strong decrease in 1997 associated with the most recent El Niño episode. In spite of high yearly variability, no long-term trend is apparent in kelp area between 1989 and 2000, suggesting that the population is stable over this time period.
- Phytoplankton blooms in central basin of Puget Sound in 1999 and 2000 were not as consistent as previous years in terms of spatial extent and timing.
- Diversity in intertidal macro-invertebrates is three times higher in northern Puget Sound relative to the southern Sound with a smooth gradient in between.

Fish

- The Washington State Department of Fish and Wildlife found in their 2000 trawl survey of groundfish in the eastern Strait of Juan de Fuca that most populations were less abundant than previously observed. Some numerically depressed species showed no population growth in response to the recent reduction of fisheries pressure.
- The trends in the status of groundfish populations for the larger Puget Sound area have improved slightly from that reported previously in the *Puget Sound Update*. However, many are still in poor condition, especially south of Port Townsend.
- NMFS determined in 2000 that the listing of seven marine fish species under ESA was not warranted, despite the sharp declines in many of these species in Puget Sound. NMFS determined the Puget Sound populations were part of larger Pacific population that, as a whole, are not declining. These seven species were the last to be considered in a 1999 petition for ESA listing that contained 18 species. A single species of that list, Pacific whiting (hake), has been retained as a candidate species pending further studies.
- The total amount of spawning herring increased modestly in Puget Sound in 2000 and 2001 although some stocks, particularly the Cherry Point stock, have shown tremendous declines and the reasons for this decline remain unknown.
- Isotopic and genetic studies of Puget Sound herring stocks, including the Cherry Point stock, were not conclusive but did not provide strong evidence in support of treating individual stocks as distinct units under ESA.
- The state Department of Fish and Wildlife observed an increase in marine survival of juvenile coho and other salmon in the Strait of Georgia in 2000. Other data suggest that this increase is associated with shifts in the food web and a decrease in predation on these species.
- Our knowledge of the status and population trends of many non-commercially valuable species remains very incomplete.
- Since the marine food web is complex, variations in populations of these undocumented species may affect the populations of those that are monitored.

Birds

- Baseline data on the pigeon guillemot population, collected in 1999-2000 as part of a new study, showed highest concentrations in the northern and southern areas with lower numbers in central Puget Sound.
- A new trend analysis of populations of wintering nearshore waterbirds in Puget Sound showed significant decrease in most species studied (grebes, cormorants, loons, pigeon guillemot, marbled murrelets, scoters, scaup, long-tailed duck and brant) between the late 1970s and the 1990s. In contrast, there was an increase in harlequin ducks and other species remained stable.

- Surveys of great blue herons conducted in 2001 showed good correspondence between data collected by aerial survey and more intensive ground surveys, suggesting the potential of expanded aerial surveys in the future. The largest numbers were seen in the northern Sound at Padilla Bay, Twassassen Ferry (B.C.) and Drayton Harbor.
- The bald eagle population in Hood Canal is increasing but still trails behind other Washington State populations in productivity.

Marine Mammals

- The sharp decline in the southern resident orca whale population continued in 2000 through 2001. This Puget Sound population declined from a recent maximum of 97 in 1996 to 78 in 2001. High contaminant levels, including PCBs, are a possible factor because they are greater than levels that have been shown to have a negative impact on other marine species. Declining food sources and artificial underwater sounds are other possible negative factors.
- In 2001, a consortium submitted a petition to NMFS to list the southern resident population of orcas, which reside for most of the year in Puget Sound/Georgia Basin, as threatened or endangered under ESA. NMFS completed a biological review and determined that protection under ESA is not warranted because the population does not meet specific criteria that are stipulated in the Act and in existing policy documents, not because NMFS contests the decline of the population.
- The state Department of Fish and Wildlife released a new trend analysis of the harbor seal population in Washington State (1978-1999) that shows an overall three-fold increase since enforcement began of the MMPA in 1978. The greatest growth has been in the San Juan Islands and the Strait of Juan de Fuca. Model analysis suggests the population is near the current carrying capacity of the inland marine ecosystem in Washington.

Exotic Species

- The Department of Natural Resources conducted a seven-day expedition in 2000 to survey exotic organisms in selected marine areas documented a total of 40 exotic species. Fewer exotic species were found in Elliott Bay and the Totten/Eld Inlet region (15 species each) compared to Willapa Bay on the outer coast (34 species).
- On this 2000 expedition, the greatest number and extent of invasions was found in the least physically altered system. This pattern appears to contradict the hypothesis that more disturbed habitats are more vulnerable to invasions.
- Coordinated efforts to control the spread of exotic *Spartina*, an invasive aquatic grass, have led to a reduction in the size of the Puget Sound infestation as a whole and the elimination in some areas.

Washington State ShoreZone Inventory

In 2000, scientists with the Nearshore Habitat Program at the Department of Natural Resources completed a statewide inventory of saltwater shorelines using the ShoreZone Mapping System.

The ShoreZone Inventory characterizes approximately 3,000 miles of saltwater shorelines statewide. Intertidal areas were surveyed between 1994 and 2000 using helicopter-based aerial videography. These recordings were then used to create geographic data that summarizes the physical and biological characteristics of the shoreline. The ShoreZone Inventory includes more than 50 parameters describing shoreline geomorphology, vegetation, and anthropogenic development. Inventory results show spatial patterns in features commonly considered to be indicators of habitat function and ecosystem condition. The data are useful for characterizing nearshore habitat at multiple scales, including the county scale for local management, and other geographic areas such as oceanographic basins.

The ShoreZone Inventory also includes data on shoreline modification (see Chapter 2).

County Name	Total Miles	Percent of Shoreline with Aquatic Vegetation: Eelgrass	Floating kelp	Non-floating kelp	Sargassum
Clallam	254	20%	40%	80%	1%
Grays Harbor	187	5%	< 1%	6%	< 1%
Island	214	63%	10%	18%	8%
Jefferson	254	58%	7%	33%	18%
King	123	62%	13%	27%	25%
Kitsap	254	48%	< 1%	21%	21%
Mason	232	28%	< 1%	24%	33%
Pacific	276	22%	< 1%	1%	< 1%
Pierce	239	26%	7%	44%	19%
San Juan	408	41%	31%	63%	47%
Skagit	229	51%	12%	26%	15%
Snohomish	133	22%	1%	1%	3%
Thurston	118	4%	< 1%	24%	4%
Whatcom	147	55%	7%	18%	34%
Puget Sound Coast	2469	43%	13%	38%	23%
Outer Coast	598	11%	9%	20%	<1%
Total	**3067**	**37%**	**11%**	**31%**	**18%**

Table 6-1. Percentage of vegetated coastal shorelines in Washington State.

Source: Washington State Department of Natural Resources

Findings

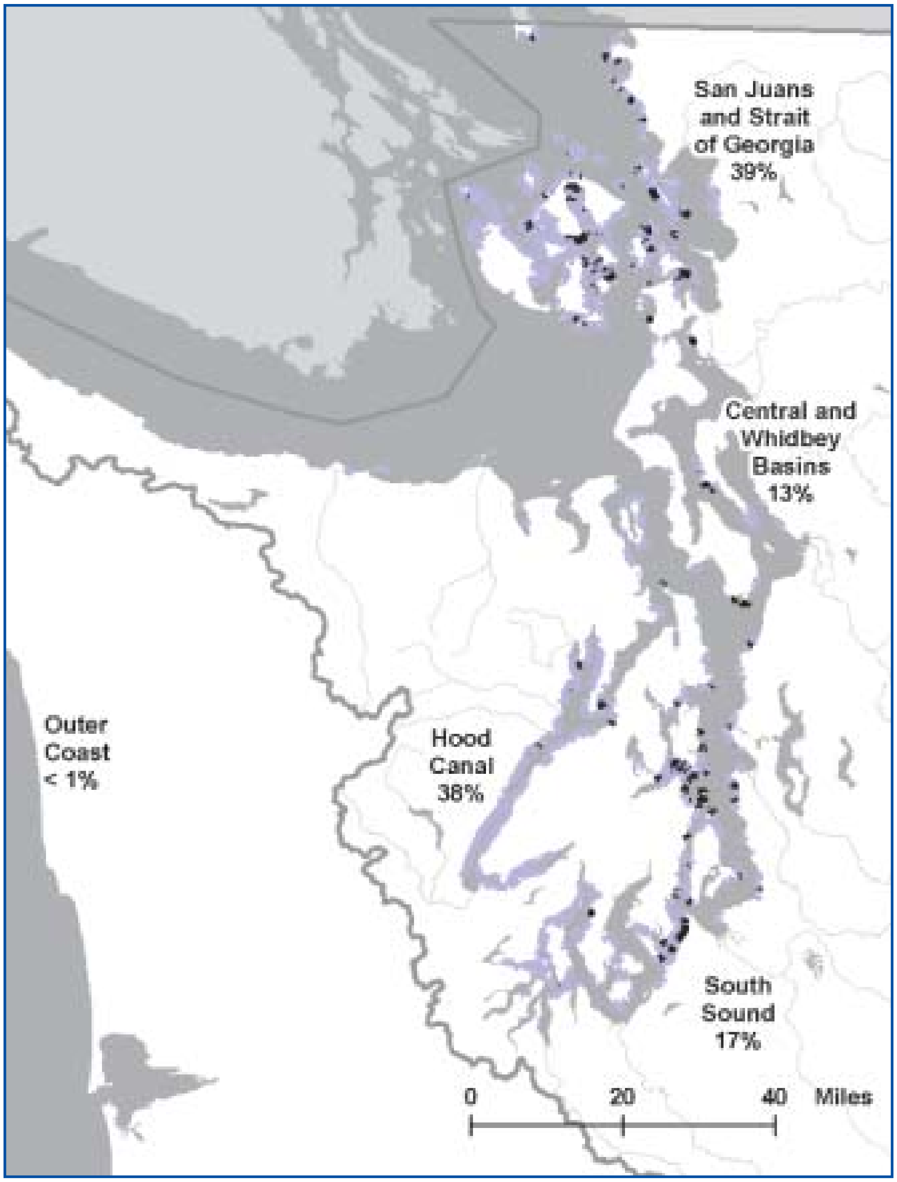
Nearshore Submerged Aquatic Vegetation

Aquatic vegetation is recognized to be important fish and wildlife habitat by ecologists and policy makers. For this reason, information on the abundance and distribution of aquatic vegetation is needed to support research and planning activities.
Table 6-1 summarizes ShoreZone Inventory data to show the relative abundance of four types of shoreline vegetation that affect habitat condition.

Eelgrass beds (*Zostera marina* and *Zostera japonica*) occur along 37 percent of shorelines. Island, King, Whatcom, Kitsap and Skagit counties have the highest percentage of eelgrass. Eelgrass is not common in South Puget Sound, and it does not occur in the extreme southern reaches, including Budd Inlet, Eld Inlet and Totten Inlet. While these data provide a useful snapshot of eelgrass distribution, they do not address temporal trends in eelgrass distribution and abundance (see Monitoring Eelgrass Abundance in Puget Sound later in this chapter).

Kelp beds are important nearshore habitats that support commercial and sport fish, invertebrates, marine mammals and marine birds. The ShoreZone Inventory shows very different patterns in the distribution of floating kelp (*Macrocystis integrifolia* and *Nereocystis leutkana*) and other non-floating kelp species (*Laminaria spp*., *Egregia menziesii* and other species). Statewide, shorelines with floating kelp are less common (11 percent) than non-floating kelp (31 percent). Floating kelp is most common in rocky, high energy environments, corresponding to high percentages of this habitat in Clallam and San Juan counties. In Jefferson County, floating kelp is common along the rocky outer coast headlands and around Port Townsend, but it is rare in Hood Canal. Floating kelp decreases gradually as energy decreases and rocky habitat becomes less common, leading to intermediate percentages in Whatcom, Skagit, Island and King counties. Floating kelp is rare in lower energy areas with predominantly sand and mud shallow subtidal substrates, including counties that border southern Puget Sound, Willapa Bay, and Grays Harbor. Like floating kelp, non-floating kelp is most common in counties with relatively high energy rocky

Figure 6-1. Percent of shoreline with *Sargassum* is shown by region.



Source: Washington State Department of Natural Resources

shorelines, such as San Juan and Clallam counties. However, non-floating kelp occurs in all counties. In protected, lower energy areas, the principal species is *Laminaria saccharina*. The lowest percentages are found in counties with extensive embayments, such as Grays Harbor, Pacific, and Snohomish counties.

Sargassum muticum is a non-indigenous brown alga from Asia. It has been known to be established in Washington for decades. However, little is known about its distribution or its interaction with local species. ShoreZone Inventory data shows that *Sargassum* is present along 18 percent of the state's shorelines, and its distribution is not even (Figure 6-1). *Sargassum* is found more often along shorelines in the Hood Canal, the San Juan Archipelago and the Strait of Georgia, leading to correspondingly high percentages in San Juan, Mason, and Whatcom counties. It is least common along the outer coast, in Clallam, Grays Harbor and Pacific counties.

Eelgrass

Eelgrass beds are important habitats because they provide substrate for many small organisms that are food for larger species, habitat for migrating salmon, and food for black brant and other waterfowl. Eelgrass also provides a source of carbon into nearshore habitats and stabilizes the sediments. Knowing how much of a resource exists and how it is changing is the first step to better protecting it for salmon and other wildlife.

Monitoring Eelgrass *(Zostera marina)* Abundance in Puget Sound

Eelgrass has been used as an estuarine health indicator in many parts of the world because it is sensitive to environmental degradation. In 2000, scientists with the Nearshore Habitat Program in the Department of Natural Resources initiated a project to assess spatial patterns and temporal trends in eelgrass habitat. Since no

	Flats (embayments)	Fringes (1,000 m segments of shoreline)	Total
n (number sampled)	14	53	67
N (number of potential sites)	72	2,420	
Basal Area Coverage (ha)	**5,436**	**5,516**	**10,951**
Percent	49.6%	50.4%	100%

Table 6-2. Estimate of basal area coverage of eelgrass in Puget Sound and the Strait of Juan de Fuca.

Source: Washington State Department of Natural Resources

single eelgrass parameter adequately describes eelgrass bed condition, several parameters are monitored: basal area coverage (number of square meters with eelgrass growing on it); maximum depth; depth range; shoot density; leaf characteristics; and patchiness of beds. Two types of eelgrass beds are defined to capture the different habitats where eelgrass occurs: fringing beds and flats. Fringing eelgrass beds occur along much of Puget Sound's shoreline, and provide a corridor for migrating salmon and other wildlife. Eelgrass also commonly grows on flats, in large shallow embayments and small pocket beaches.

In 2000, 67 sites were surveyed throughout Puget Sound using underwater videography (Table 6-2). The results provide valuable baseline information on current eelgrass bed characteristics and on how to optimize sampling for long-term monitoring. Preliminary research results are reported here, while the final report is being completed.

There are approximately 11,000 hectares (27,180 acres) of native eelgrass *(Z. marina)* in Puget Sound. This estimate was derived from probabilistic sampling and consistent methods; therefore, it can be used for change detection. In order to maximize the monitoring program's ability to detect statistically significant changes in eelgrass, the Department of Natural Resources analyzed sources of variation and optimized future sampling efforts. After optimization, the scientists found that at the current level of effort, the monitoring program will be able to detect as little as a 20 percent change in eelgrass abundance over a 10-year monitoring period. With higher levels of funding, it would be possible to detect finer scale and regional differences.

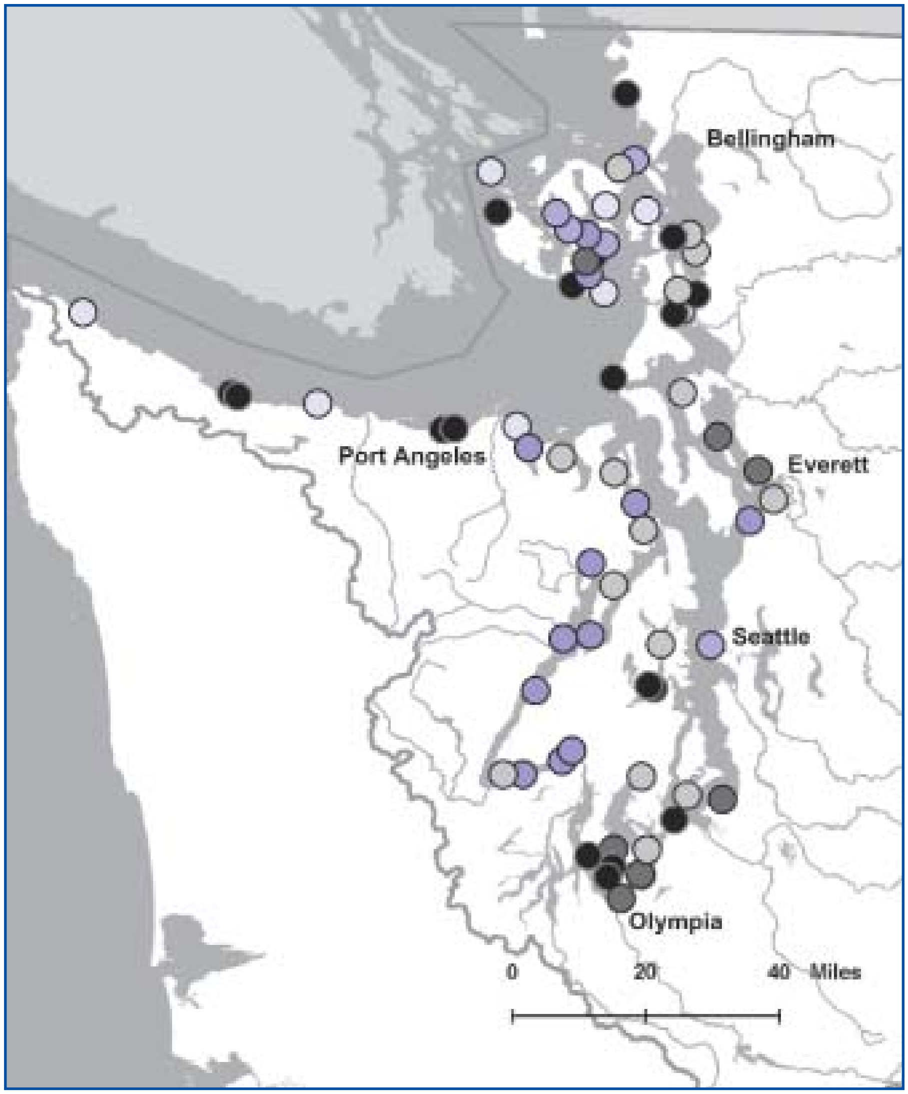
The relative proportion of eelgrass in fringing beds and flats was previously unquantified. These data show an even distribution between flats and fringes, roughly half of the eelgrass occurs in each habitat type. However, eelgrass is not evenly distributed across the landscape; roughly one-fifth of the eelgrass grows in one large flat—Padilla Bay.

Another parameter measured by the monitoring program is maximum depth. The maximum depth of eelgrass beds is related to light availability in the water column. It can change in response to changes in water quality. Water quality is affected by many factors including natural events such as storms that re-suspend sediments, and human influences such as dredging and fertilization from urban run-off containing fertilizers. In Puget Sound, the Department of Natural Resources found that the mean maximum depth of eelgrass beds ranged from 2.5 feet (0.76 meters) below Mean Lowest Low Water (MLLW) to more than 24 feet (7.3 meters) in depth, with a median depth of -10 feet (–3.0 meters) (Figure 6-2). Overall, there was a general trend of deeper beds found nearer to oceanic waters and shallower beds in southern Puget Sound. Smaller scale gradients were associated with factors such as slope of the shore, substrate changes, and proximity to river mouths. Riverine influenced areas tend to have higher levels of suspended solids that affect light penetration in water column. Scientists at the Department of Natural Resources believe that higher levels of suspended solids in the southern Puget Sound, relative to the northern areas with greater oceanic influence, explain the shallower depths of eelgrass beds in southern

Figure 6-2. Maximum depth of eelgrass beds in Puget Sound.

Max Depth
- -20 to -25 feet
- -15 to -20 feet
- -10 to -15 feet
- -5 to -10 feet
- 0 to -5 feet
- no depth data

Source: Washington State Department of Natural Resources



Sound. This hypothesis was supported by the finding that maximum depths of eelgrass beds were negatively correlated with water column light attenuation.

Unlike eelgrass in other parts of the world, eelgrass beds throughout the region are diverse and heterogeneous. For example, the density ranged from sparse to dense: 23 to more than 1,000 eelgrass shoots per square meter. Leaf lengths of this underwater plant were as small as 10 centimeters to as large as 2 meters. Some beds in Puget Sound were large continuous meadows, while others consisted of many discrete patches surrounded by bare sand and mud. Using several metrics to describe eelgrass beds will allow this monitoring program to capture how this resource is changing over time.

Temporal Trends in the Areal Extent of Canopy-forming Kelp Beds Along the Strait of Juan de Fuca

Kelp beds are important nearshore habitats that support commercial and sport fish, invertebrates, marine mammals and marine birds. Many factors, both natural and anthropogenic, affect the extent and composition of kelp beds. For example, elevated water temperature and intense sea urchin grazing can decimate kelp beds. El Niño events stress kelp by producing severe winter storms and reducing upwelling events, which normally replenish the nutrients in the water column. Human influences on kelp beds include sewage and other runoff that decrease water quality by changing the

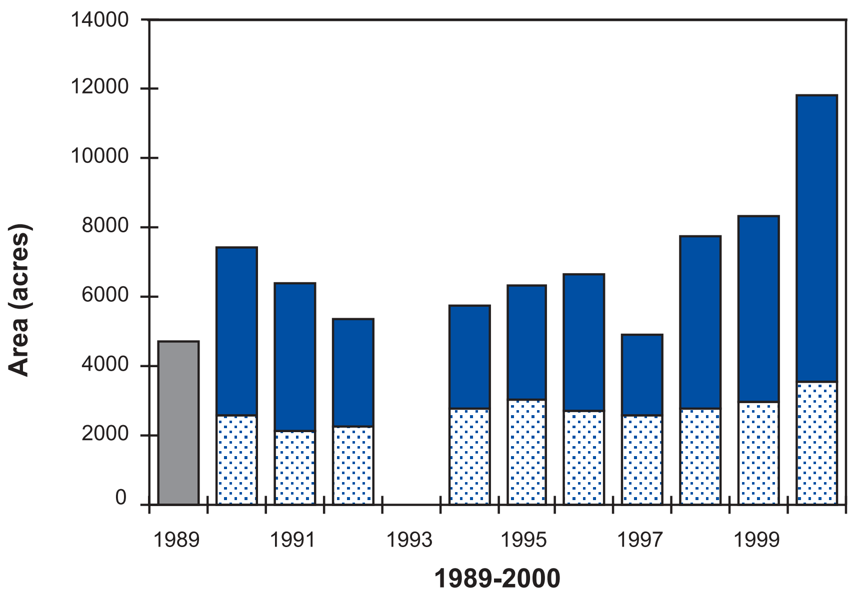


Figure 6-3. Kelp bed area in the Strait of Juan de Fuca, 1989-2000. No data were collected in 1993.

no species data

Nereocystis

Macrocystis

Source: Washington State Department of Natural Resources

nutrient levels and reducing light in the water column. Kelp plants also can be physically damaged by boat propellers and fishing gear. Commercial harvest of kelp is not a significant factor in Washington State due to a law prohibiting this practice.

Since 1989, scientists with the Department of Natural Resources have conducted annual inventories of canopy-forming kelp beds in the Strait of Juan de Fuca using aerial photography. This long-term dataset helps us to understand how the extent of kelp canopies changes over time. In addition to tracking overall changes in bed extent, the dataset differentiates patterns and trends in the extent of two species that make up canopy-forming kelp beds—giant kelp (*Macrocystis integrifolia*) and bull kelp (*Nereocystis luetkeana*). The scientific challenge is to differentiate the natural yearly fluctuation in this dynamic population from changes due to human impacts or due to local or regional environmental conditions.

Analysis of the 1989 through 2000 dataset for the Strait of Juan de Fuca shows that the areal extent of kelp varied highly from year to year (Figure 6-3). Changes in kelp extent were significantly different in seven out of the 10 yearly comparisons (95 percent confidence interval). The extent of kelp was lowest in 1989 (1,911 hectares, or 4,722 acres) and greatest in 2000 (4,788 hectares, or 11,832 acres). Because of high yearly variability, the increases over the last 4 years were not statistically significant and no long-term trend is apparent between 1989 and 2000. This suggests that the population is stable over this time period. When compared to beds on the outer coast, the Strait of Juan de Fuca kelp beds did not always exhibit similar changes in canopy extent over time, suggesting different responses to regional environmental conditions. For example, kelp bed extent throughout the study area was lowest in 1997, as compared to the lowest extent in 1989 for the Strait of Juan de Fuca alone.

While the population appears stable over the study area as a whole, some local losses of kelp are evident. One bed of concern is north of Protection Island near Port Townsend. It gradually dwindled from 181 acres in 1989 and disappeared in 1997. After two years of absence, 39 acres of kelp were observed at this location in 2000. This site is of special interest because local human impacts are presumed to be minimal; the island is a National Wildlife Refuge and access to the upland area is limited.

Species composition of the canopy-forming kelp beds varied greatly from year to year, reflecting the different responses of bull kelp and giant kelp to environmental conditions. Bull kelp canopies covered a larger area in nine out of 10 years monitored along the Strait of Juan de Fuca, as compared to seven out of 10 years in the study area as a whole. Bull kelp consistently had lower fractional cover ranging from 0.19 to 0.38, compared to giant kelp cover which ranged from 0.34 to 0.51. Bull kelp populations showed much higher year-to-year variation in total extent. The higher cover and relative year-to-year stability of the giant kelp population is attributed in part to life cycle differences. Giant kelp is a perennial that regrows yearly from its holdfast, and spores tend to disperse locally. Bull kelp is an annual, and its spores tend to disperse more widely, leading to greater year-to-year changes in its distribution and abundance.

In 1997, during an El Niño event, kelp canopy area throughout the study area decreased by 32 percent. Scientists are now trying to understand the relationship between the kelp population and this regional climate perturbation. In 1997, losses were highest in the bull kelp (*Nereocystis luetkeana*) populations along the outer coast, which experienced 75 percent loss. Over the same area, giant kelp (*Macrocystis integrifolia*) populations decreased by 8 percent. During the subsequent year, 1998, the overall floating kelp population increased by 87 percent, and the outer coast bull kelp populations increased by 423 percent. Kelp bed extent increased throughout the study area in both 1999 (11 percent) and 2000 (41 percent).

Phytoplankton

King County monitors chlorophyll-*a* concentrations as an indicator of phytoplankton abundance. Concentrations were measured from the surface down to a depth of 35 meters monthly at several offshore stations (from Admiralty Inlet to Colvos Passage) in the central Puget Sound basin in 1999 and 2000.

Although maximum concentrations vary from year to year, phytoplankton blooms usually occur in April or May and July in the central basin. Phytoplankton blooms in 1999 and 2000 were not as consistent as seen in previous years with blooms noted in some areas but not others and at different times of the year. For example, in 1999 phytoplankton blooms occurred in May, June and September at most stations in the central basin, with a large bloom in September (Figure 6-4). A bloom at Admiralty Inlet occurred in October—the latest month in which a bloom has been seen. In Possession Sound, a bloom was evident in April but not in June or July. In 2000, phytoplankton blooms were evident in May, June and August at all stations monitored. The northern area of the central basin (including Admiralty Inlet and southern Possession Sound) also exhibited a bloom in April that was not seen in other areas. Although the May and June blooms appear to be relatively consistent for both 1999 and 2000, the timing of the late summer/early fall bloom was variable. Additional sampling at stations in the northern part of the central basin for 1999 and 2000 indicates that phytoplankton blooms occur earlier there than other areas in the central basin.

The Washington State Department of Ecology also evaluates chlorophyll, but data more recent than 1997 were not yet available for this report. For information about the Department of Ecology's characterization of phytoplankton based on monitoring through 1997, please see the 1998 and 2000 *Puget Sound Updates* and the Department of Ecology's technical reports.

Intertidal Communities

Intertidal biological communities are made up of a diverse set of resident invertebrates and plants that respond to changes in a wide range of physical, chemical and biological conditions. It is important to monitor intertidal biological communities for their intrinsic biodiversity value and also because these communities have an impact on other organisms through the food web. Biological community monitoring is commonly used nationwide to study sites that have been disturbed by contamination. As interest mounts in monitoring nearshore habitat condition for salmonids and other species, the biological community is increasingly being used as a general measure of habitat health in local and regional projects.

Intertidal Biota

Spatial Patterns of Intertidal Biological Communities in Central and South Sound

Scientists with the Nearshore Habitat Program in the Department of Natural

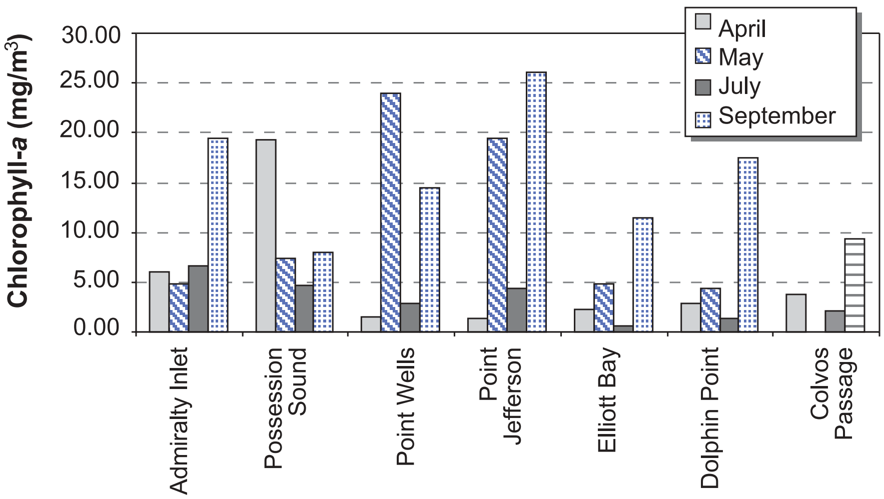


Figure 6-4. Occurrence of phytoplankton blooms at stations from north to south in 1999 for selected months.

Source: King County Department of Natural Resources and Parks

Resources have been studying intertidal biological communities in Puget Sound since 1997. The project goals are:

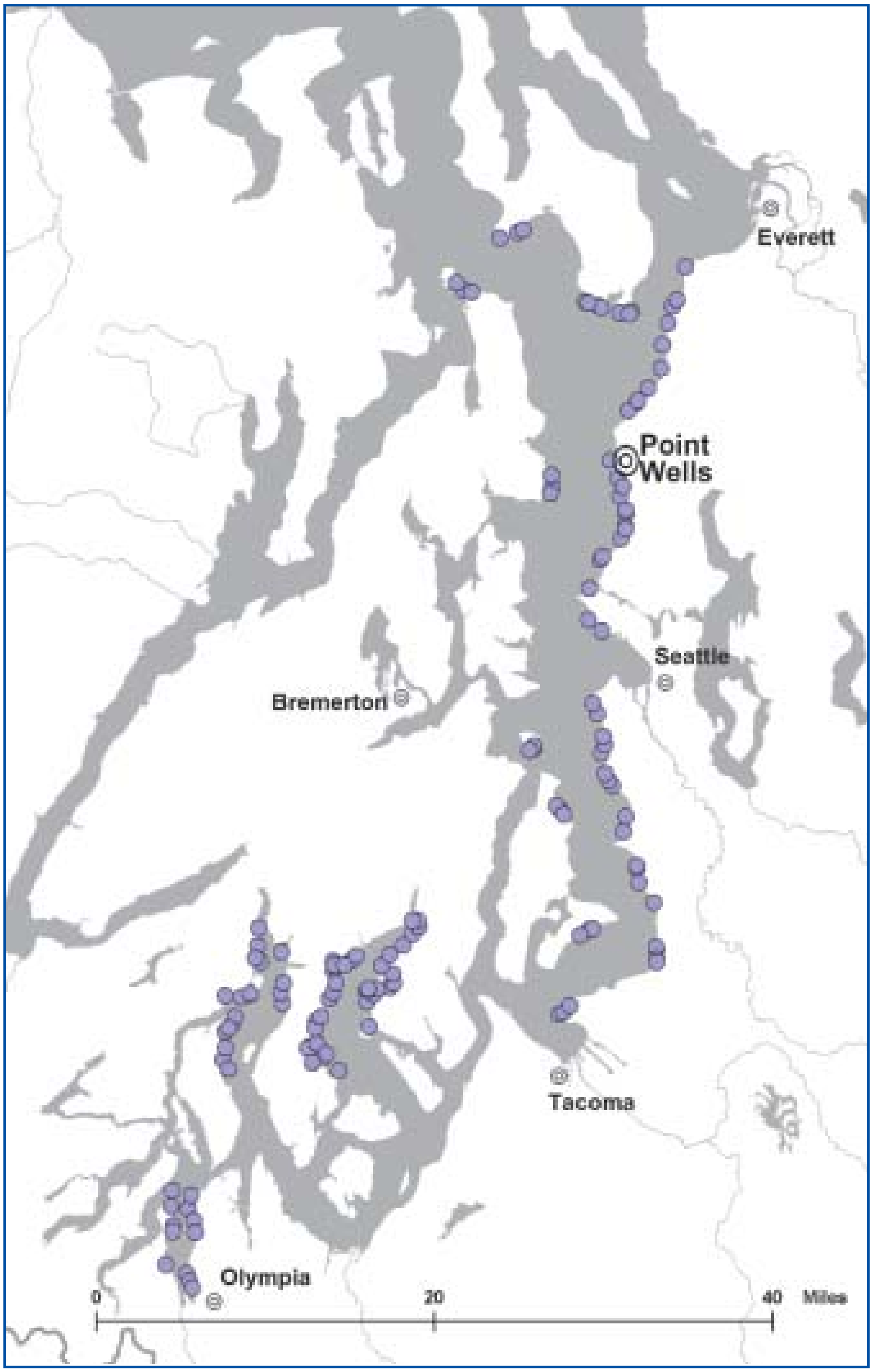
1. To collect baseline information on community patterns in Puget Sound.
2. To determine if the intertidal biological community is a suitable indicator of habitat condition for PSAMP.
3. To provide large-scale, contextual information for comparison to more detailed studies.

The biological community monitoring project samples organisms living on and in the substrate in the lower intertidal zone. In 1997, samples were collected in Carr Inlet. Since then, the geographic extent of the project has gradually expanded to include Case Inlet, Budd Inlet and central Puget Sound (Figure 6-5). Results from this work reveal spatial patterns and temporal trends in community structure. They also bring important considerations to light for groups who are considering monitoring biological communities:

- Species richness (the number of species present at a site) is a common measure of habitat condition. In Puget Sound, this study documented striking gradients in species richness over large spatial areas. Species richness was generally three times greater in the north, as shown by comparison of pebble beaches sampled between Olympia and southern Whidbey Island. Transitions in species abundance along this gradient were gradual as opposed to abrupt, suggesting that the basins of Puget Sound represent parts of a continuum. These patterns were shown in both the surface biota and the infauna.
- Interannual variation in biota is high. However, while temporal variation within the organisms on a beach is found from one year to the next, similar beaches within an area tend to change in the same ways and remain similar to each other. This finding has an important implication for other studies that compare multiple sites to gauge habitat condition: study designs should select sites that are nearby and compare data from the same year as much as possible.
- Comparison of recent surveys to historical surveys suggests change has occurred at some sites. Data from the central Sound were compared qualitatively to historical surveys from the 1970s and

Figure 6-5. Intertidal biological community sampling sites.

Source: Washington State Department of Natural Resources



1980s to assess whether there had been major shifts in the communities over time. In general, the historical surveys showed a high degree of overlap in flora and fauna. One exception was found in the beaches near Point Wells near Edmonds. Many taxa found in the historical surveys from Point Wells sampling sites were conspicuously missing from the recent surveys. Additionally, these beaches had lower richness and fewer juvenile clams compared to recent surveys of sites to the north and south. Possible causes of these absences include nearby pollution, other anthropogenic influences, or unusual substrate conditions occurring in the last 20 years.

- Samples of different habitat types reveal broad patterns in biotic communities that relate to physical conditions. For example, a total of 197 invertebrate and algal species were found in 1998. Mud beaches had the most species overall (91), followed by pebble (81), cobble (73) and sand (59). The average number of species per habitat type was highest for complex substrates including pebble (14.0) and cobble (8.5), and lowest for sand (3.5) and mud (6.2). These findings can be used to select the best habitat types to monitor, and to provide context for other studies. Generally, change detection is most likely to be successful in habitat types that have consistently high diversity.
- Because scientists lack the resources to sample biological communities everywhere, managers would like to be able to extrapolate data collected at sampled beaches to unsampled sites. In the event of a localized impact, such as an oil spill, the effects of that spill could then be assessed via detailed sampling of physically similar beaches that were not impacted. One goal of this study was to successfully extrapolate biological community results to unsampled beaches. The approach to meet this goal was to randomly select beaches and classify their physical characteristics in detail. To test whether these beaches were more widely representative, additional beaches were selected and compared to the original beaches. The comparisons showed that the organisms on the new beaches were very similar (statistically indistinguishable) from those beaches already sampled. This means that, in the case of an oil spill or other accident, the data would illustrate (with high statistical confidence) the biota that should have been on the beach before the spill.

Deep Puget Sound Benthos

A U.S. Geological Survey scientist recently analyzed a nearly 30-year record of sediment-dwelling organisms in central Puget Sound "to examine the concept of long-term stability in a deep-water (200m) community." (Nichols 2001). The analysis showed that the most abundant species were consistently present over the period studied, 1963 to 1992. However, the study also reveals a gradual change in the community indicated by changes in observed species composition and abundance of organisms, including:

1. Aperiodic, multi-year bursts in the abundance of the common species.
2. An overall increase in the total abundance of the benthic community beginning in the mid-1970s.
3. Periods of increased abundance, during the late 1970s and early 1980s, of two species that are tolerant of organic enrichment.
4. The surprisingly steady decline in abundance of the large burrowing echinoderm, *Brisaster latifrons*.

The researcher notes that these are conspicuous changes but that there are no obvious environmental factors to readily explain them. Circumstantial evidence suggests changes in climate, organic enrichment, and predator abundance as possible influences. The researcher concludes that the principal reasons for our inability to identify causes of long-term change in the sediment-dwelling organisms of Puget Sound are (1) presumed natural biological variability and (2) inconsistent long-term monitoring of environmental variables (i.e., related to changes in monitoring programs over time).

The results of this study underscore the need for consistent long-term data on biologically relevant environmental variables that scientists can use to analyze changes in key biological populations. This type of data and subsequent analysis will be needed to help us to understand the influences of human-caused environmental stressors and corrective actions.

Fish

In a recent review, the American Fisheries Society concluded that "the recovery of fish stocks at risk in Puget Sound appear to be the most complex in North America." (Musick et al., 2000). This review identifies eight species of marine fish in Puget Sound to be "at risk," meaning they face some risk of extinction or they risk falling into such a category in the near future.

Table 6-3 summarizes the Society's findings about these eight species. The review also identifies a number of other species at risk over a larger geographic area including the marine waters of Washington State. The Society's review relied heavily on data from marine fish monitoring similar to that described below.

Petition for Listing Puget Sound Marine Fish under the Endangered Species Act

In February 1999, NMFS received a petition for 18 species of marine fish that are found in Puget Sound to be considered as threatened or endangered under the provisions of ESA. A retired state Department of Fish and Wildlife employee developed the petition using stock assessments and other information developed by Fish and Wildlife staff as the basis of the petition. Besides Pacific herring, the other species were groundfish species that have been identified by Fish and Wildlife as in critical or depressed status in Puget Sound.

In June 1999, NMFS accepted the petition as meriting further consideration but limited the petition list to only seven species that were likely to have data available for a biological opinion. The seven species were Pacific herring, Pacific cod, walleye pollock, Pacific whiting (hake) and copper, brown and quillback rockfish. Since this initial determination, state Department of Fish and Wildlife staff consulted with NMFS numerous times to provide survey, stock structure and biological information that were important in the deliberations. During November 2000, NMFS announced its final decision regarding the ESA listings for codfishes and found that listings are not warranted for Pacific cod and walleye pollock populations from Puget Sound (Gustavson et al. 2000). NMFS did, however, retain Pacific whiting (hake) as a candidate species pending further genetic and other studies. Decisions were made for the remaining species in the spring of 2001. NMFS concluded that none of the other petitioned rockfishes and Pacific herring warranted listing (Table 6-4; Stout et al. 2001a, 2001b). In these cases, NMFS made this determination despite the sharp declines in many of these species in Puget Sound because the Puget Sound populations were found to be part of larger Pacific populations that as a whole are not declining.

Although none of the petitioned species warranted listing, the various panels of scientists and biologists reviewing the petition expressed concern about widespread, nearly synchronous decline of several fish species in Puget Sound. These declines include not just the petitioned marine fish, but some salmonid species as well. Joint consideration of the implications of these declines is beyond the scope of the ESA but may indicate ecosystem-level changes in Puget Sound. Such changes would be of deeper concern than the decline of any single species. The review teams pointed out the need to determine if these changes are anthropogenic (i.e., caused by fishing, habitat loss, etc.) or natural (caused by environmental variation and general ecosystem dynamics) and the overall significance of any ecosystem-level change.

Table 6-3. Marine fish at risk in Puget Sound as identified by the American Fisheries Society (Musick et al. 2000).

Species	Risk Category	Risk Factors / Comments
Copper rockfish	vulnerable	very low productivity; long-term decline since mid-1980s; spawner output decline >80% from 1979 to 1992
Brown rockfish	vulnerable	probable low to very low productivity; long-term decline since mid-1980s
Quillback rockfish	vulnerable	very low productivity; long-term decline
Black rockfish	vulnerable	low to very low productivity; long-term decline; has become rare
Pacific cod	vulnerable	Low productivity; may form localized spawning aggregations; vulnerable to overfishing; declined 80 to 90% since 1970s; no evidence of recovery despite fishing regulations; recovery may be hampered by warming water temperatures
Walleye pollock, South Puget Sound	endangered	low productivity; vulnerable to overharvesting; may be extirpated; fishery collapsed in 1988 and no specimens in recent trawl surveys; northern Puget Sound may be overharvested but not at risk
Pacific hake, South Puget Sound	vulnerable	low productivity; local concentrated South spawning aggregations vulnerable to heavy overharvesting; survey biomass declined from 45 million pounds in 1983 to 1 million pounds in 1998; high predation by pinnipeds may prevent recovery despite stringent fishing regulations
Pacific herring	vulnerable	medium productivity; evidence for metapopulation structure with stock aggregations spawning at specific sites; 4 of 8 stocks may have declined from overharvesting, annual natural mortality increased from 20 to 80% because of increased pinneped predation

Table 6-4. ESA listing status for marine fish species for Puget Sound.

Source: Washington State Department of Fish and Wildlife

Common Name	Scientific Name	Status
Pacific herring	*Clupea pallasi*	Not warranted
Pacific cod	*Gadus macrocephalus*	Not warranted
Pacific whiting (hake)	*Merluccius productus*	Candidate
Walleye pollock	*Theragra chalcogramma*	Not warranted
Copper rockfish	*Sebastes caurinus*	Not warranted
Quillback rockfish	*S. maliger*	Not warranted
Brown rockfish	*S. auriculatus*	Not warranted

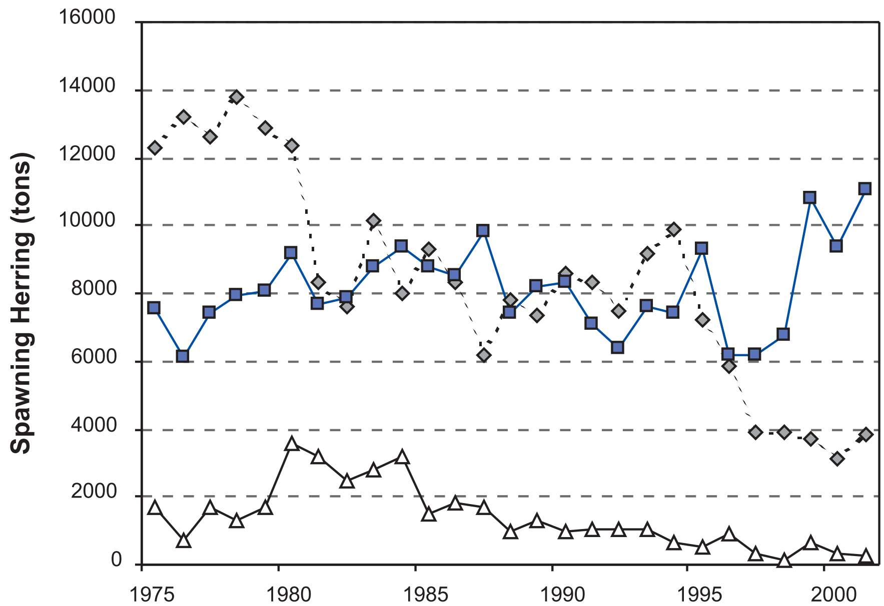
Figure 6-6. Annual Puget Sound herring run, 1975 to 2001.

◆ North Sound

■ Central/South Sound

△ Straits

Source: Washington State Department of Fish and Wildlife



Pacific Herring in Puget Sound

The overall abundance of spawning Pacific herring (*Clupea pallasi)* in Puget Sound has increased from the low levels observed in the mid 1990s. Despite this overall increase, a few spawning stocks remain at low levels of abundance (Figure 6-6), especially the stocks spawning at Cherry Point (near Bellingham) and Discovery Bay.

The management of Pacific herring by the state Department of Fish and Wildlife is based on the stock concept. The department recognizes 19 herring stocks in the Puget Sound region, based largely on the location and timing of spawning aggregations. This is an increase of one stock since the publication of the *2000 Puget Sound Update*. An additional spawning ground was located in Hale Pass, south of the Tacoma Narrows Bridge. Herring spawning at this site have been reported to Fish and Wildlife in earlier years, but previous surveys had not detected any spawning activity. However, in 2000, a survey was conducted very early in the year, and spawning was detected. The amount of herring using this location in 2000 was small—140 tons of adults.

The total amount of spawning herring in Puget Sound was 12,800 tons in 2000 and 15,100 tons in 2001. These levels represent an increase from the 10,000 to 11,000 tons spawning annually in 1997 and 1998. This increase is largely due to increases in abundance at spawning grounds in Puget Sound south of Port Townsend.

Scientific studies coordinated by the state departments of Fish and Wildlife and Natural Resources are improving our understanding of Pacific herring in Puget Sound. Results of two Fish and Wildlife-funded studies provide evidence that the stock of herring that spawns in the spring near Cherry Point appears to be biologically distinct from other herring stocks in Puget Sound and the Georgia Basin. Results from a third study, funded by the Department of Natural Resources, indicate that herring larvae from the Cherry Point stock have lower survival potential than do larvae from other stocks in the region.

The Cherry Point stock, once the largest of these stocks, has seen substantial declines in recent years. For example, the spawning biomass of the Cherry Point stock declined from more than 4,000 tons in 1995 to 808 tons in 2000. This dramatic decline coupled with the potential effects of existing and proposed industrial development along the Cherry Point shoreline led to a number of investigations of the Cherry Point herring stock.

The state Department of Fish and Wildlife recently commissioned a pair of studies to investigate: (1) isotopic signatures in the bones of adult herring that can provide information on the environment in which the fish hatched and grew and (2) genetic variations in various Puget Sound stocks of Pacific herring. Significant results include:

1. Isotopic signatures in herring bones
The ratios of carbon and oxygen isotopes incorporated in the otoliths (ear bones) of adult herring soon after they hatched indicate that spawning herring collected at Cherry Point were hatched in a different environment than were adult herring collected from Port Orchard (central Puget Sound) and Squaxin Pass (south Puget Sound). The isotope ratios were similar in fish collected from Port Orchard and Squaxin Pass. This indicates that adult herring returning to spawn at Cherry Point experienced a different environment as newly hatched fish than did those adults spawning at Squaxin Pass and Port Orchard. This fidelity to spawning/hatching location implies that herring stocks may be threatened by environmental stresses occurring at the spawning/hatching location.

2. Pacific Herring—Genetic Analysis of Population Structure
In 2001, the state Department of Fish and Wildlife initiated a genetic study to obtain additional information about the number, geographic locations, and interrelationships of herring stocks. This study consisted of two parts, one was an investigation of micro-satellite DNA variation conducted by Fish and Wildlife staff and the other was a study of sequence variation in mitochondrial DNA conducted by Dr. Paul Bentzen at the University of Washington.

The micro-satellite DNA investigation analyzed seven collections: three collections of the Cherry Point stock (south of Birch Bay, Strait of Georgia spawners in April 1999; non-spawners in April 1999; spawners in May 2000); and individual collections of the Johnson Point stock (south Puget Sound, January 1999), the Fidalgo Bay stock (Padilla Bay, north Puget Sound, February 1999); the Semiahmoo stock (west of Birch Bay, Strait of Georgia, February 1999); and a collection from the Northumberland Channel in British Columbia (in the Strait of Georgia northwest of Nanaimo, February 1999). Twelve micro-satellite DNA loci were screened in a total of 692 fish. The investigation revealed significant differences between most pairs of collections suggesting there may be multiple genetically differentiated stocks of Pacific herring in the Puget Sound region while the similarity between the 1999 and 2000 Cherry Point stock collections (spawners) suggest that the genetic characteristics of at least this stock may be stable from year to year.

Sequence analysis of a 572 base pair portion of the mitochondrial DNA in 313 herring from six collections (1999 Cherry Point [2 collections], Johnson Point, Semiahmoo, Northumberland, and Port Gamble) revealed 82 different genetic types (haplotypes). Overall there was little evidence of heterogeneity among the six collections. While these data are consistent with the micro-satellite DNA data that indicate a genetic difference between the Cherry Point stock and the other stocks tested, they do not provide evidence for the existence of other genetically differentiated stocks of herring in the region. Staff at the Canada Department of Fisheries and Oceans (Pacific Biological Station, Nanaimo) have analyzed micro-satellite DNA variation in collections of Pacific herring from many Canadian localities. In general, the genetic differences observed among sites in the Strait of Georgia along the east side of Vancouver Island, are no larger than those observed within sites in different years. Thus, although there is evidence of genetic heterogeneity among collections, the heterogeneity does not seem to have a strong geographic basis, and does not appear to establish the existence of multiple, genetically differentiated stocks in this region.

Taken together, these studies of the genetics of Pacific herring in the Puget Sound region suggest the existence of multiple stocks but do not provide unambiguous proof that distinct stocks exist. Additional analysis employing more collections (annual repeats and additional localities) and possibly more loci may resolve the present uncertainty.

The findings of these state Department of Fish and Wildlife studies underscore the importance of studying the condition of Pacific herring spawning at Cherry Point. One study funded by the Department of Natural Resources (Hershberger and Kocan 2000) investigated the survival potential of herring larvae from Puget Sound, with special attention to the Cherry Point stock. The study found indications of decreased survival potential for Cherry Point herring as indicated by reduced larval hatch weights, greater percentage of larval skeletal abnormalities and insufficient larval yolk reserves at time of hatch. Causes remain undetermined, but Hershberger and Kocan have suggested that decreased age and size of adult spawners might partially explain the reduced fitness of Cherry Point herring larvae.

Recent Increase in Salmon Production in the Strait of Georgia

There was a major increase in early marine survival of juvenile coho and other Pacific salmon species in 2000 in the Strait of Georgia. This increase is most clearly seen in the July 2000 abundance of ocean age 0 coho although there are smaller increases for other species of juvenile salmon (Figure 6-7). We refer to this period in the salmon life cycle as the early marine period, thus the increased survival represents increased early marine survival.

The September 2000 data do not reflect the same relative increase in abundance seen in July 2000. In September 2000, there were 5.4 times the coded-wire tagged (CWT) coho captured per unit of effort outside of the Strait of Georgia than in any of the previous three years. This indicates that in 2000, juvenile coho were leaving the Strait of Georgia earlier than in the previous three years. Scientists with Fisheries and Oceans Canada (Beamish et al. 2001b) propose that the change in behavior is related to the improved growth, the greater abundance of coho, and possibly the greater densities of chum and pink salmon juveniles. The increased survival was associated with increased size and fitness.

There also was a major increase in euphausiid biomass and individual size, a common prey species for salmon and other predators. These changes suggest a more generalized increase in productivity in 2000 in the Strait of Georgia that could have important impacts throughout the food web. Beamish et al. (2001b) propose that the improved juvenile salmon survival was a result of reduced predation-based mortality. Previous work (Beamish et al. 2001a, 1992) showed that spiny dogfish (*Squalus acanthius*) are a major predator of salmon smolts when smolts first enter the Strait of Georgia. Spiny dogfish also feed on euphausiids, and Beamish et al (2001b) propose that the increased abundance of euphausiids may have provided alternate, and even preferred alternate prey, reducing predation on coho.

The dramatic improvement in production of coho and organisms at lower trophic levels, as well as the suggested shift in predation patterns that occurred in 2000 were associated with a dramatic change in climate. In 1998 there was a rapid change from El Niño conditions to a La Niña state (McPhaden 1999). These results suggest that the dynamics of salmon production can change abruptly in response to regional climate related processes and the direct impacts on the food web.

Puget Sound Groundfish

Groundfish are the marine fish species that live near or on the bottom for most of their adult lives. More than 150 species occur in Puget Sound, which once supported

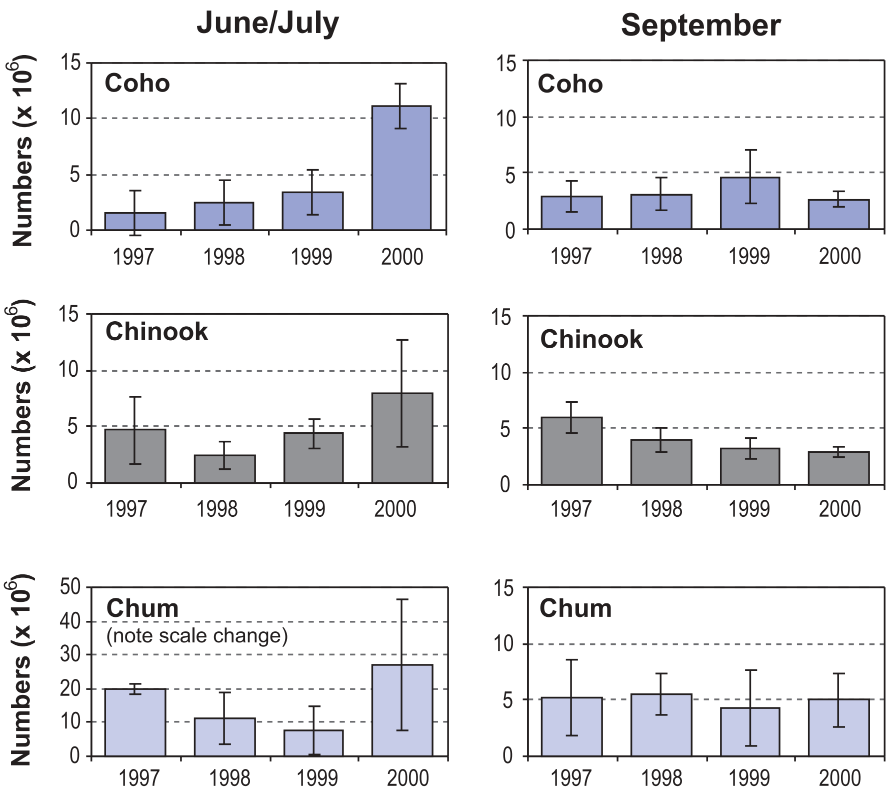


Figure 6-7. Abundance of ocean age 0 coho, chinook, and chum in eight surveys, 1997-2000. Error bars represent plus and minus two standard deviations of the mean.

Source: Fisheries and Oceans Canada

thriving commercial and recreational fisheries for groundfish. During recent times, many key groundfish populations have declined to alarming levels. The state Department of Fish and Wildlife is committed to conserving the local stocks of these fish and has enacted a number of stringent measures to promote stock rebuilding.

The methods to determine status and trend for Puget Sound groundfish stocks are in transition changing from information based upon fisheries to information based upon demographic and survey information. Many of the key species were assessed by methods developed primarily from information supplied by recreational or commercial fishers (Palsson et al. 1997). The time series of the fishing success can be used as an indicator of the relative population strength for groundfish species if the chance of catching a fish doesn't change over the assessment period. For some species such as rockfish, extreme changes in regulations prevent the use of fishing success as a relative population indicator. In other cases, fishery-dependent data may not accurately reflect population trends when fishing technology improves, or when market conditions change the nature of the fisheries. This edition of the *Update* includes much of the updated trend information from fishery data but also expands other data series including measures of reproduction over time and population abundance estimates from bottom trawl and acoustic surveys. For all of these time series, a comparison of the most recent two-year average indicators was made to historical or long-term averages of the indicators. Percent changes were categorized into five measures of stock status:

- Above average (change greater than 6 percent above average)
- Average (within 5 percent of average)
- Below average (6 percent to 35 percent less than average)
- Depressed (36 percent to 75 percent less than average)
- Critical (at least 76 percent less than average)

In the cases of sablefish, Pacific halibut and Pacific whiting in the Strait of Georgia, other stock assessments were used to infer population status in Puget Sound waters.

Most assessments were conducted separately for groundfish in north Puget Sound (north of Port Townsend to Sekiu and the Canadian border) and south Puget Sound (south of Port Townsend). Beginning with this *Update*, many stock evaluations are provided for basins within the inland marine waters of Washington. The assessments made for each basin should be considered tentative at this time pending a more full review of the data quality, statistical variability, and population dynamics.

In a preliminary 2002 assessment of the status of Puget Sound groundfish stocks (Table 6-5), state Department of Fish and Wildlife scientists find only a slight improvement in the status of these stocks compared to reports in recent years. In 2002, an equal number of stocks are listed in healthy condition as are listed in poor condition. As has been reported in previous Updates, south Sound has a greater proportion of stocks in poor condition (55 percent) than north Sound (44 percent). Among the basins, the Strait of Georgia-San Juan Archipelago has the greatest number of healthy stocks and south Sound the smallest. With the use of survey data and more specific fishery data, many of the previously unknown stock conditions are becoming resolved for Puget Sound.

Many species are thriving in the basins of Puget Sound including most of the flatfishes in the north Sound and lingcod in the San Juan archipelago and in the south Sound. English sole, starry flounder, rock sole, sand sole and skates are species targeted by bottom trawl fisheries in the north Sound and appear to be in above average condition in the Straits of Georgia and Juan de Fuca. Lingcod in the San Juan Archipelago are rebounding from very poor population conditions experienced in the mid-1990s. However, they are still in a depressed status in the Strait of Juan de Fuca, which is closer to coastal stocks that are in poor condition. Lingcod populations are in above average condition in central and southern Puget Sound basins as well as the Whidbey Basin. Species and species groups that are not sought as much by commercial and recreational fishers appear to be doing well. Spotted ratfish, greenlings, and sculpins are in average or above average condition in most basins. Other groundfish appear to be healthy in the north Sound and its basins.

Pacific halibut stocks are assessed on a larger scale than just for Puget Sound, and their populations continue to be in above average condition in the southern region (William Clark, International Pacific Halibut Commission, Personal Communication). Some important groundfish species continue to be in poor condition. Rockfishes in both the north and south Puget Sound are in depressed condition based on fishery-derived data, demonstrating a drastic decline in abundance or size during the past 25 years (Figure 6-8 and Figure 6-9). For copper rockfish, the primary indicator reflecting these changes has been the estimated spawning potential (Figure 6-10), which is a surrogate measure of the spawning biomass. The spawning potential is approximated by combining the relative change in populations (based upon catch rates) and the estimated fecundity of copper rockfish applied to observations of lengths in the recreational fishery. In both the north and south Sound, the recent spawning potential has declined approximately 75 percent since the historical peaks estimated during the 1970s. Many management authorities consider declines of more that 60 percent of the natural spawning potential as signs of population stress.

The sharp decline observed in fishing success and spawning potential in 2000 most likely reflects a new regulation instituted by the Fish and Wildlife Commission, which decreased the allowable daily take of rockfish from five in the north Sound and three in the south Sound to just one fish in almost all areas of Puget Sound.

Species	North Sound	Str. Georgia & SJ Is.	Str. Juan de Fuca	South Sound	Hood Canal	Central Sound	Whidbey Basin	Southern Sound
Spotted ratfish	below average	above average	below average	above average	above average	above average	unknown	above average
Spiny dogfish	depressed	depressed	depressed	depressed	critical	critical	unknown	critical
Skates	above average	above average	above average	depressed	depressed	below average	unknown	depressed
Pacific cod	below average	depressed	critical	critical	critical	critical	critical	critical
Walleye pollock	above average	above average	above average	critical	unknown	critical	critical	critical
Pacific whiting (hake)	unknown	average	unknown	critical	unknown	critical	critical	unknown
Rockfishes	depressed	unknown	unknown	depressed	unknown	unknown	unknown	unknown
Lingcod	below average	above average	depressed	above average	unknown	above average	above average	above average
Sablefish	below average	below average	below average	below average	below average	below average	below average	below average
Greenlings	above average	above average	above average	above average	unknown	above average	unknown	critical
Sculpins	above average	above average	above average	above average	above average	above average	unknown	above average
Wolf-eel	unknown	unknown	below average	average	average	average	unknown	average
Surfperches	below average	above average	depressed	depressed	above average	critical	unknown	critical
English sole	above average	above average	above average	below average	below average	average	unknown	below average
Rock sole	average	above average	above average	average	above average	average	unknown	average
Starry flounder	above average	above average	above average	average	above average	depressed	unknown	below average
Dover sole	depressed	critical	below average	depressed	above average	depressed	unknown	depressed
Sand sole	average	above average	above average	above average	above average	above average	depressed	depressed
Pacific halibut	above average	above average	above average	above average	above average	above average	above average	above average
Other groundfish	average	above average	above average	below average	above average	below average	unknown	below average
No. of Healthy Stocks	10	14	10	9	10	9	2	6
No. of Poor Stocks	8	4	8	11	5	9	4	12

Table 6-5. Preliminary status assessments of groundfish populations in Puget Sound.

North Sound includes the Strait of Georgia, the San Juan archipelago and the Strait of Juan de Fuca

South Sound includes Hood Canal, central Sound, Whidbey basin and southern Sound (south of Tacoma Narrows)

above average
average
below average
depressed
critical
unknown

Source: Washington State Department of Fish and Wildlife

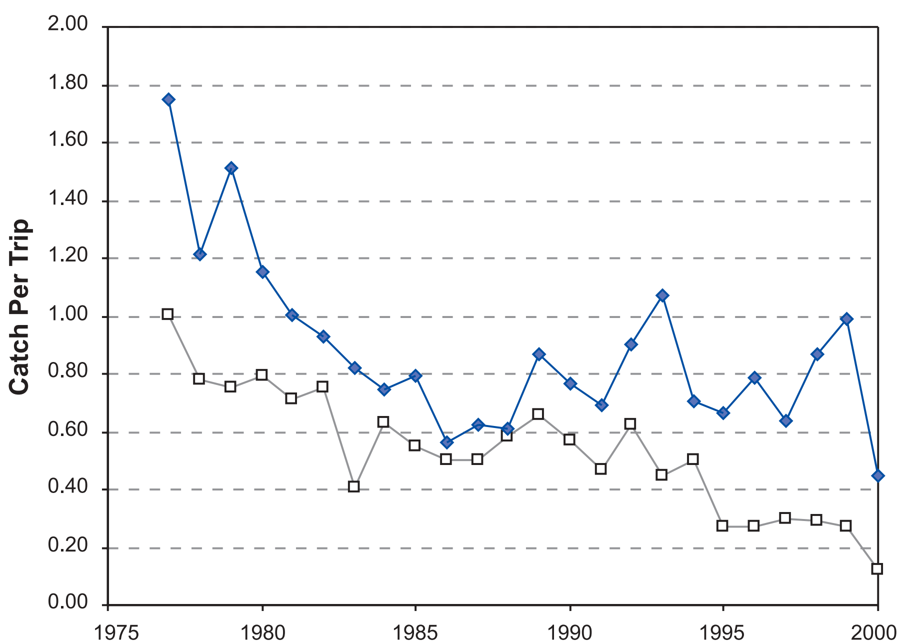
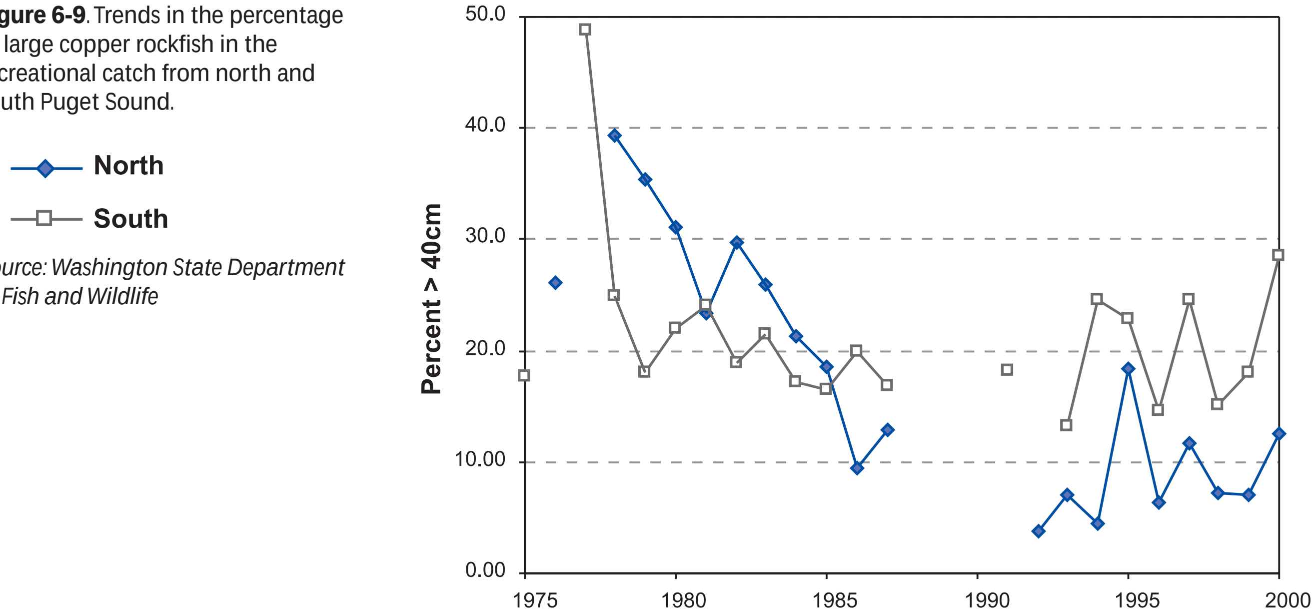


Figure 6-8. Recreational fishing success for rockfish in north and south Puget Sound.

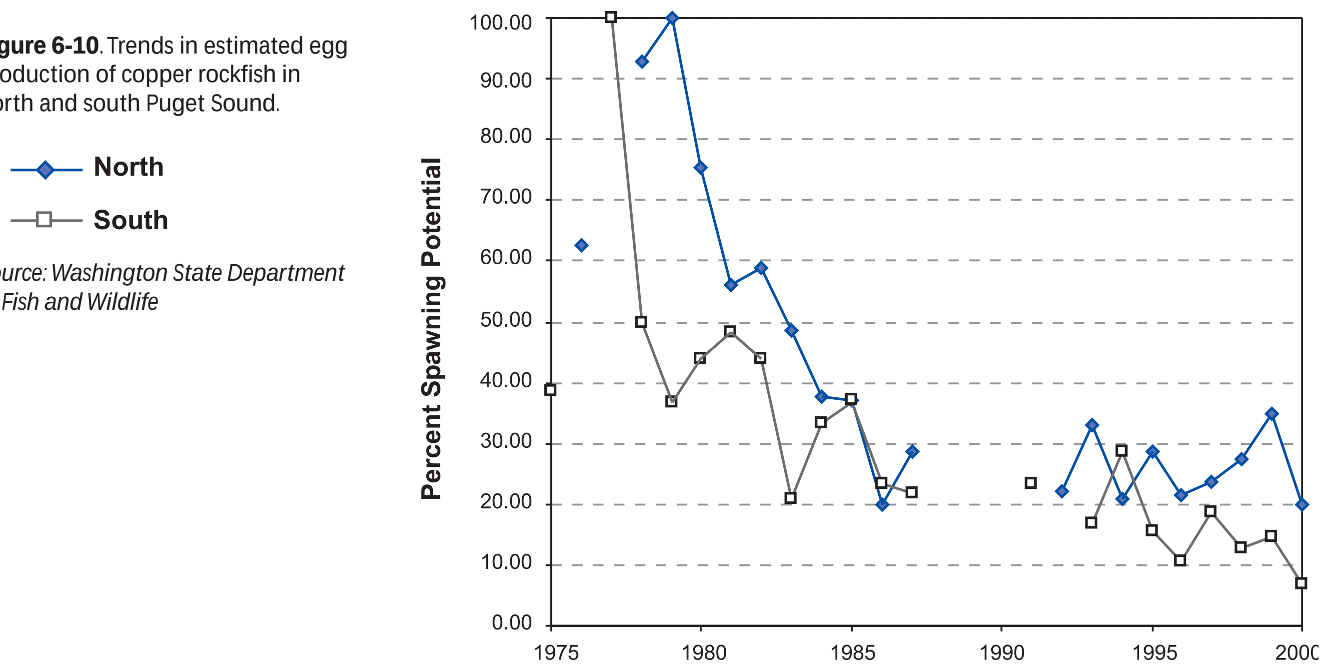
Source: Washington State Department of Fish and Wildlife

Figure 6-9. Trends in the percentage of large copper rockfish in the recreational catch from north and south Puget Sound.



Source: Washington State Department of Fish and Wildlife

Figure 6-10. Trends in estimated egg production of copper rockfish in north and south Puget Sound.



Source: Washington State Department of Fish and Wildlife

While not reflected in these assessments, black rockfish appear to be making a local resurgence in the western Strait of Juan de Fuca and daily catch limits were increased based upon sustainable fishing modes in this area to take advantage of the increased abundance of this species.

Other groundfish species in poor condition include Pacific cod in the north and south Sound, Pacific whiting (hake) in the south Sound, and walleye pollock in the south Sound. Whiting in the Strait of Georgia are shared in common with Canada, and Canadian stock assessments find that whiting are in stable condition in the Strait of Georgia (Saunders and McFarlane 1999).

Spiny dogfish is a small shark sought by commercial fishers but is considered a nuisance by recreational fishers. Both fishery and trawl survey indicators show this species is depressed or in critical status in all areas of Puget Sound.

A number of species are in poor condition in south Sound including skates, surfperches, and Dover sole. Dover sole also appear to be in poor condition in the north Sound.

Sablefish mostly occur as juveniles in Puget Sound, and have become uncommon, as coastal stocks have declined. Coastal assessments of sablefish indicate they are below 40 percent of their unfished levels (Pacific Fishery Management Council) and are listed as below average for Puget Sound status.

A Trawl Survey of the Eastern Strait of Juan de Fuca and Discovery Bay. During May 2000, the state Department of Fish and Wildlife conducted a synoptic bottom trawl survey of the eastern Strait of Juan de Fuca and Discovery Bay in the transboundary waters of Washington and British Columbia. The stratified systematic survey was designed to estimate the numerical and biomass abundances of key benthic species, identify population trends, and quantify the impact of fisheries. The survey was also designed to describe the distribution of key commercial fishes that inhabit the Strait of Juan de Fuca and determine which are likely to move across the international boundary and are vulnerable to fisheries on either side of the border.

The survey included the collection of 40 trawl samples from 1,400 km^2 of the Washington Strait of Juan de Fuca and 25 samples collected in the 463 km^2 of the B.C. Strait of Juan de Fuca (Figure 6-11). A special survey of Discovery Bay included 12 trawl samples in the 31 km^2 study area.

Scientists collected 72 identifiable species of fish during trawling exclusive of the Discovery Bay survey. They collected 67 species of fish in Washington, and 48 fishes in B.C. An estimated 35,600 individual fish were caught during the trawl survey, and they weighed 7.9 metric tons (mt). Thirty-three species of fish were collected during the 12 trawls conducted in Discovery Bay. There was an estimated population of 132.2 million fish weighing 27,000 mt living in the eastern Strait of Juan de Fuca. Washington contained 112 million bottomfish while B.C. had 20 million individuals. The B.C. bottomfish resource constituted an estimated 8,000 mt while the Washington resource weighed an estimated 19,000 mt. As expected, Discovery Bay had far fewer fish than either of the two larger survey areas. There was a fish population of 2.9 million fish weighing and estimated 90 mt in Discovery Bay. Density, distribution, length, and population information was also collected on many large benthic invertebrates including Dungeness crab and shrimp.

Spotted ratfish made up more than 75 percent of the fish populations in Washington and B.C. Flatfish as a group was the second most dominant species group in Washington, while a complex of other species contributed to the diverse catches found in B.C.

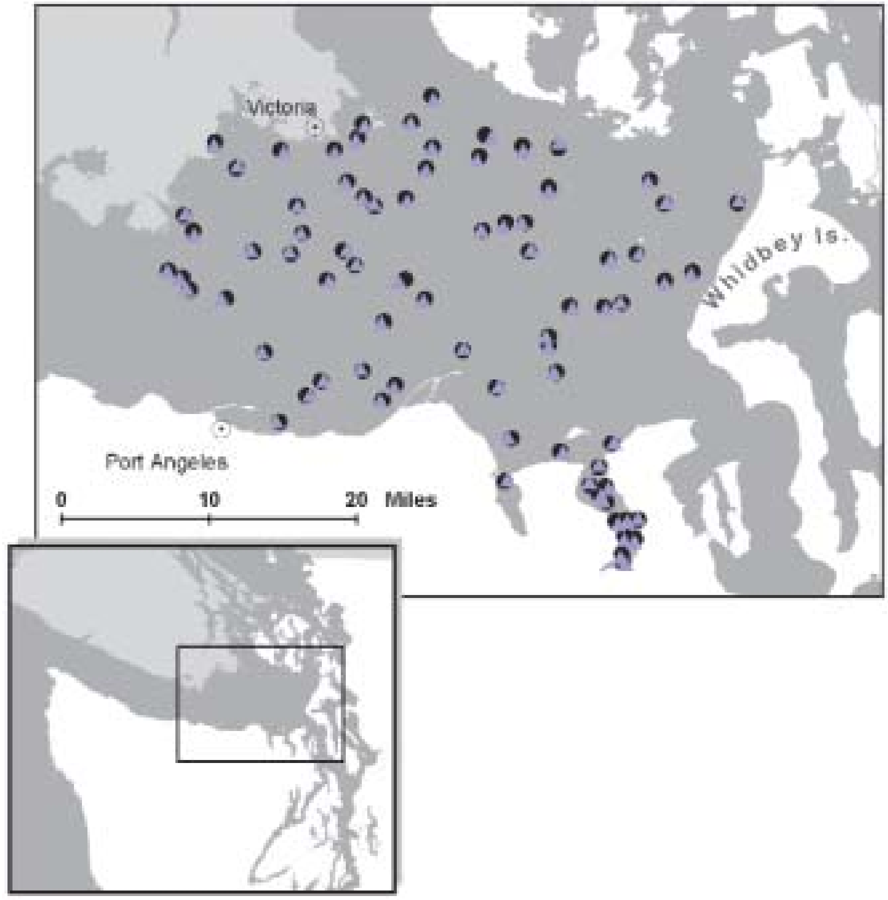
Overall, most populations were less abundant than estimated during previous surveys of the Washington Strait of Juan de Fuca (Figure 6-12). Depressed species such as Pacific cod and lingcod appear to show no response to the reduction of pressure from fisheries in recent years. However, both species almost uniformly were small, indicating strong survival has occurred in preceding years. Discovery Bay contains almost exclusively juvenile and small individuals of key species once harvested in commercial bottom trawl fisheries.

The geographic distribution and depth preferences of key species and invertebrates result in a complex pattern for transboundary management. The shallow banks and deep basins in the central Strait provide habitat for both deep and some shallow waters species resulting in a wide and continuous distribution spanning the international boundary (Figure 6-13). These continuous distributions indicate that

Figure 6-11. Planned and actual stations occupied during the 2000 Trawl Survey of the Eastern Strait of Juan de Fuca and Discovery Bay.

▲ Actual
● Planned

Source: Washington State Department of Fish and Wildlife



coordination between Washington and Canada will become important if substantial fisheries re-develop in the area.

A comprehensive assessment and management approach for groundfish is outlined in the Puget Sound Groundfish Management Plan adopted by the Fish and Wildlife Commission in June 1998 (Palsson et al. 1998) for non-tribal fisheries and resources. This plan implements the precautionary policy for managing Puget Sound groundfish adopted by the Commission several years earlier. The state Department of Fish and Wildlife has implemented many management actions to conserve and protect the declining populations identified by groundfish stock assessments. Such actions include reducing the number of allowable harvests of fish, closing areas to fishing, and eliminating directed fisheries. Further conservation and harvest plans will be developed as Fish and Wildlife forges co-management agreements for groundfish with the treaty tribes of Puget Sound.

Marine Birds and Waterfowl

Trends between 1978-1979 and 1992-2000 in wintering nearshore waterbirds

The marine bird component of PSAMP has used aerial surveys to monitor wintering nearshore marine birds in Puget Sound since 1992. State Department of Fish and Wildlife scientists compared density estimates from a subset of the PSAMP survey transects with those from the nearly identical winter aerial survey transects conducted during 1978 and 1979 in the northern portion of greater Puget Sound (Figure 6-14). The 1978-1979 study was part of the Marine Ecosystem Analyses (MESA) program administered by National Oceanic and Atmospheric Administration (NOAA) and funded by the U.S. Environmental Protection Agency

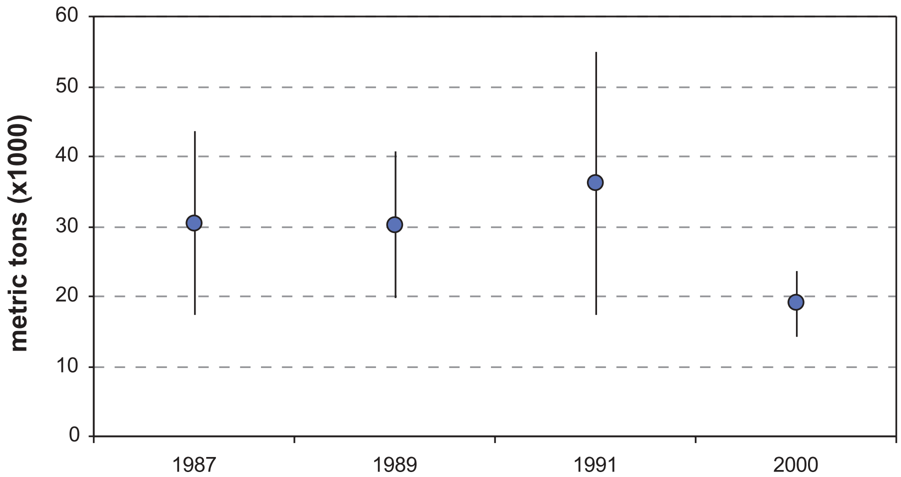


Figure 6-12. Estimated biomass (metric tons) and 95 percent confidence limits for all fish in the Washington Eastern Strait of Juan de Fuca.

Source: Washington State Department of Fish and Wildlife

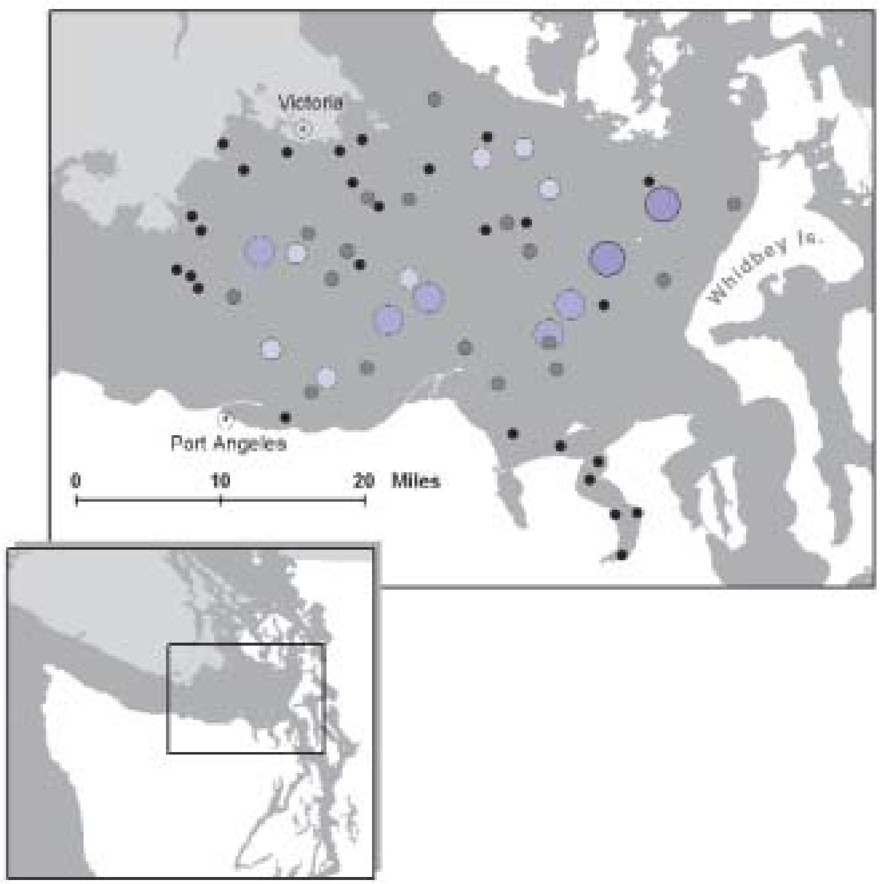


Figure 6-13. The transboundary distribution of walleye pollock in the eastern Strait of Juan de Fuca in kilograms per hectare.

0.1 - 1
1 - 5
5 - 10
10 - 25
25 - 43

Source: Washington State Department of Fish and Wildlife

(EPA). Trends in changing densities during the last 20 years were examined for 18 species or species groups (Figure 6-15, Figure 6-16, Figure 6-17): scoters, scaups, goldeneyes, bufflehead, long-tailed ducks, harlequin ducks, mergansers, all loons combined, common loon, western grebe, red-necked grebe, horned grebe, all cormorants combined, double-crested cormorant, brant, all gulls combined, pigeon guillemot and marbled murrelet. The results include a mixture of changes that range from significant decreases (grebes, cormorants, loons, pigeon guillemot, marbled murrelets, scoters, scaup, long-tailed ducks and brant) to stable or more slowly decreasing patterns (goldeneyes, buffleheads, and gulls) or increasing patterns (harlequin ducks and, probably, mergansers).

Waterfowl. The comparison of data from nearly identical MESA and PSAMP aerial transects indicates statistically significant decreases in densities for scoters (57 percent), scaup (72 percent), and long-tailed duck (91 percent), while showing significant increases for harlequins (189 percent increase). Changes for the other three species of diving ducks examined were not statistically significant (goldeneyes, bufflehead and mergansers). The MESA/PSAMP comparisons suggest a statistically significant decline in brant densities (66.3 percent).

Grebes and Loons. Western grebes appear to have declined even more so than diving duck species. In fact, all the loon and grebe species examined have experienced marked and statistically significant decreases in the MESA/PSAMP comparisons: red-necked grebe (89 percent decrease); horned grebe (82 percent decrease); common loon (64 percent decrease); or all loons combined (79 percent decrease).

Alcids. Comparisons are possible for both pigeon guillemots and marbled murrelets since they frequent the nearshore depth included in the comparable MESA and PSAMP transects. Even though aerial surveys miss some of these birds, especially marbled murrelets, the comparisons of densities seen on aerial surveys in both MESA and PSAMP efforts suggest statistically significant declines for these two species: pigeon guillemot (55 percent decline) and marbled murrelet (96 percent decrease).

Cormorants and Other Species. While wintering cormorant densities did not appear to change much during the PSAMP period, densities have decreased significantly between the MESA and PSAMP periods, either for identified double-crested cormorants (62 percent decrease) or for all cormorants including the unidentified category (53 percent decrease). It is unknown whether cormorants return to similar wintering areas each winter. The inner marine waters of Washington State are home to many other resident marine species as well as attracting many other wintering bird species, such as numerous gull species. The decrease in gull densities comes closest to significance.

Scientists have observed definite changes in bird populations during the last 20 years among the varied marine bird species that winter in greater Puget Sound, including many significant declines in numbers and densities. It is uncertain whether documented changes relate to cycles of change such as the North Pacific Decadal Oscillation or to more local changes in forage fish stocks. Bird species that either eat fish or depend upon certain spawning events of Puget Sound forage fish appear to have declined more than species that emphasize feeding on other parts of the food chain, such as crustaceans and invertebrates. The declines in scoters and scaup in Washington State have also been similarly documented in other marine areas throughout the Pacific Flyway. This suggests that they have not moved from Washington to some other part of their wintering range.

Monitoring of Breeding Pigeon Guillemots

To obtain an accurate estimate of pigeon guillemot population trends in Puget Sound, breeding colony censuses were conducted during 1999 and 2000 (the first years of a 5-year study). These boat surveys obtained partial coverage of all colonies within the inland marine waters of Washington State in 1999 because much of the effort was to identify colony locations. The 2000 surveys provided complete coverage of the colonies. Survey participants included the Olympia PSAMP staff from both the state Department of Fish and Wildlife and the U.S. Fish and Wildlife Service; staff from the U. S. National Wildlife Refuges; the Whale Museum; and regional staff and volunteers of the state Department of Fish and Wildlife.

The surveyors counted birds at colonies during May and June 1999 and May 2000. All counts were conducted by vessel from sunrise to 3.25 hours after sunrise, at sea

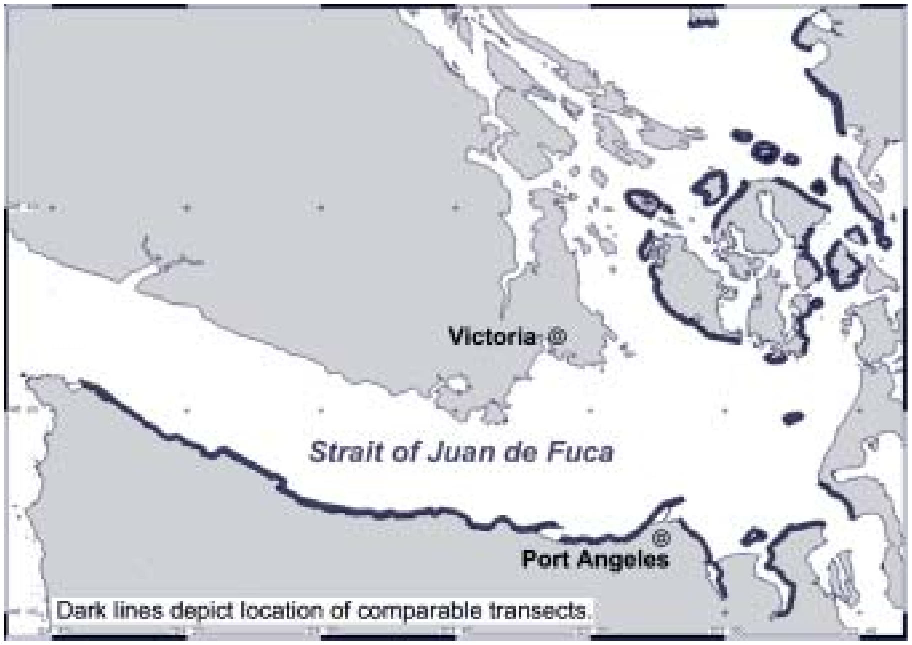


Figure 6-14 . Transect locations for comparisons of marine bird densities derived from aerial surveys conducted by MESA and PSAMP.

Source: Washington State Department of Fish and Wildlife

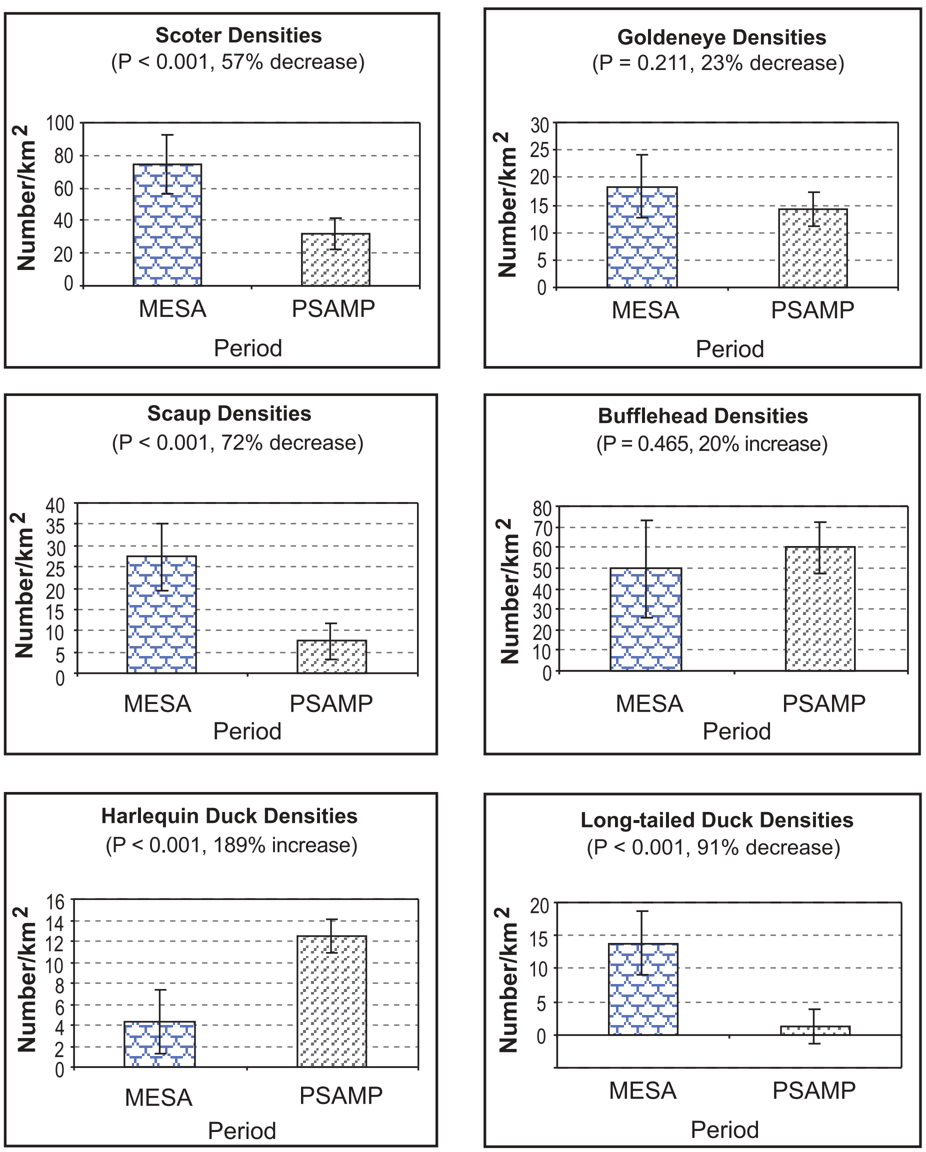
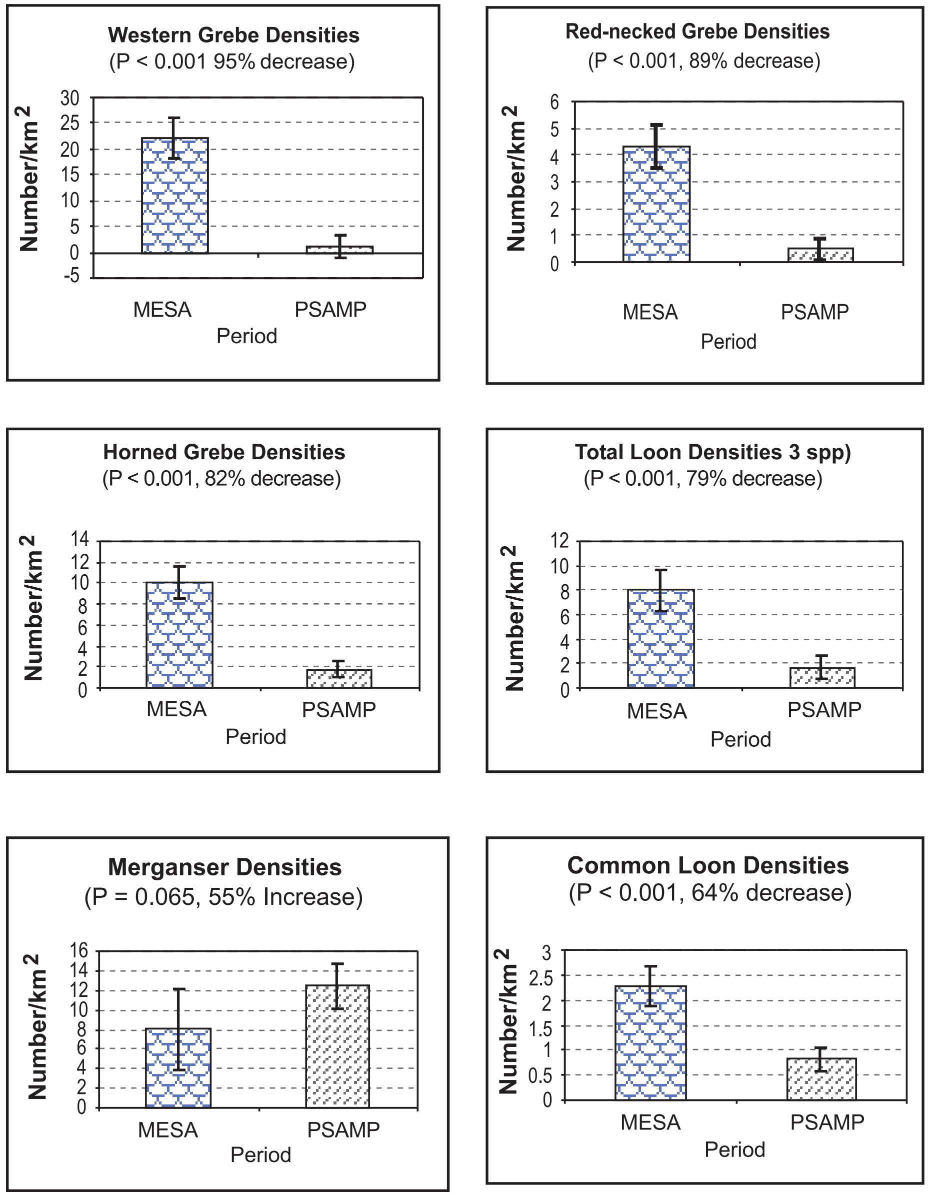


Figure 6-15. Changes in density (birds/km^2) of selected diving duck species observed on nearly identical transects between the 1978-1979 MESA and the 1992-1999 PSAMP aerial surveys.

Source: Washington State Department of Fish and Wildlife

Figure 6-16. Changes in density (birds/km^2) of grebe, loon and merganser species observed on nearly identical transects between the 1978-1979 MESA and the 1992-1999 PSAMP aerial surveys.

Source: Washington State Department of Fish and Wildlife



states of less than or equal to Beaufort 3. All guillemot colonies listed in the *Washington Catalog of Seabird Colonies* (Speich and Wahl 1989) were counted. During 1999, counts occurred during May and June, with special emphasis to search for, and count, colonies not listed in the Colony Catalog; a minimum of one count was conducted in May at the colonies listed in the colony catalog. However, efforts were made to get three counts per colony. During 2000, areas not searched in 1999 for unlisted colonies were investigated in April, and all colony counts were conducted during May only, with an average of three counts at each colony.

The surveyors conducted counts at 273 colonies (maximum count of 9,172 guillemots) in May 1999 (Figure 6-18), with colonies previously listed (Speich and Wahl 1989) comprising 120 of these (6,740 guillemots counted). Figure 6-19 shows the 429 colonies counted during May 2000 (14,852 guillemots counted), with colonies previously listed comprising 121 colonies (7,840 guillemots counted) (Table 6-6). The maximum count of guillemots, at the 269 colonies counted during both years was 9,121 and 10,380, from 1999 and 2000 respectively. A total of 308 colonies, not previously recorded in the *Catalog of Washington Seabird Colonies*

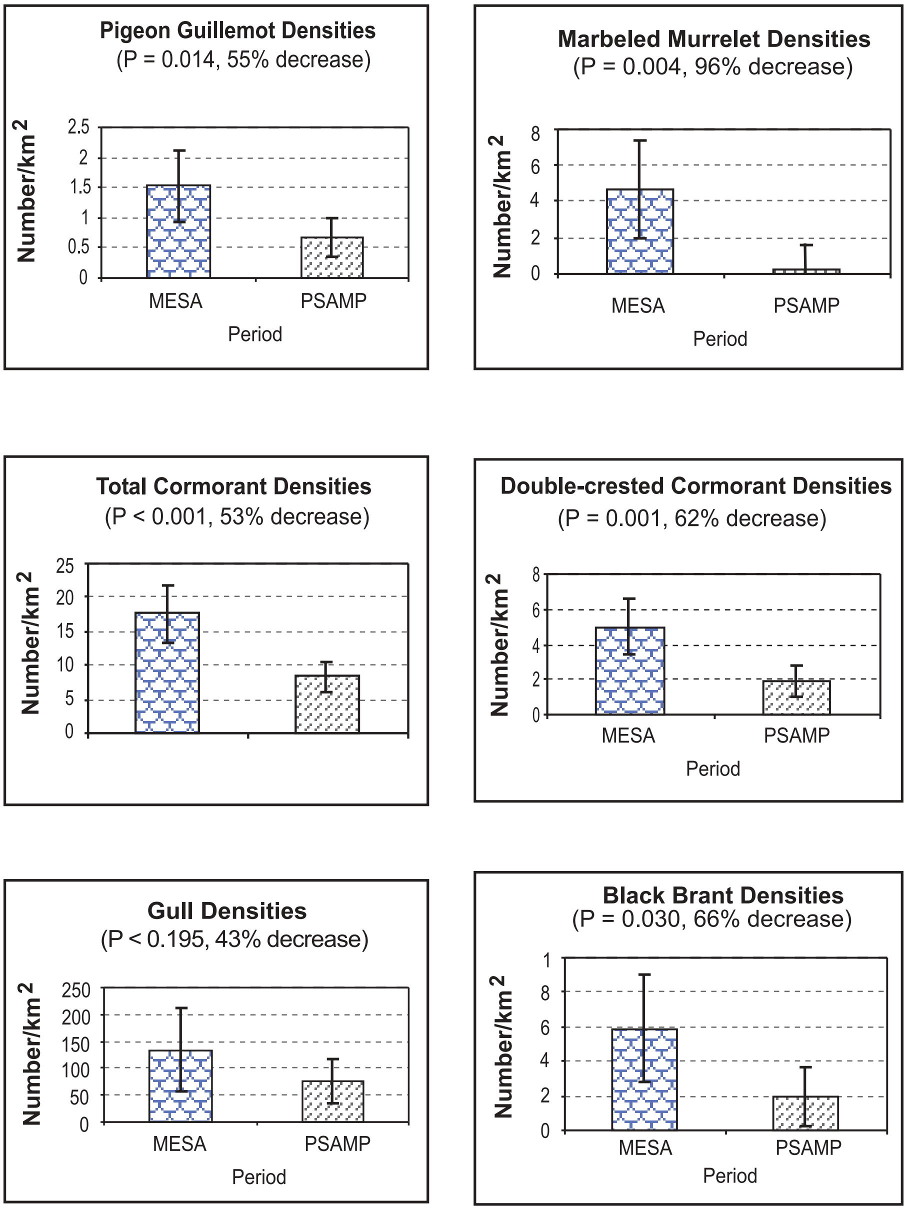


Figure 6-17. Changes in density (birds/km^2) of alcid, cormorant, gull and other species observed on nearly identical transects between the 1978-1979 MESA and the 1992-1999 PSAMP aerial surveys.

Source: Washington State Department of Fish and Wildlife

(Speich and Wahl, 1989), were documented, adding over 89 percent to the total number of breeding guillemots known. The importance of counting smaller colonies was apparent; 62 percent of the colonies in 2000 had 25 birds or fewer.

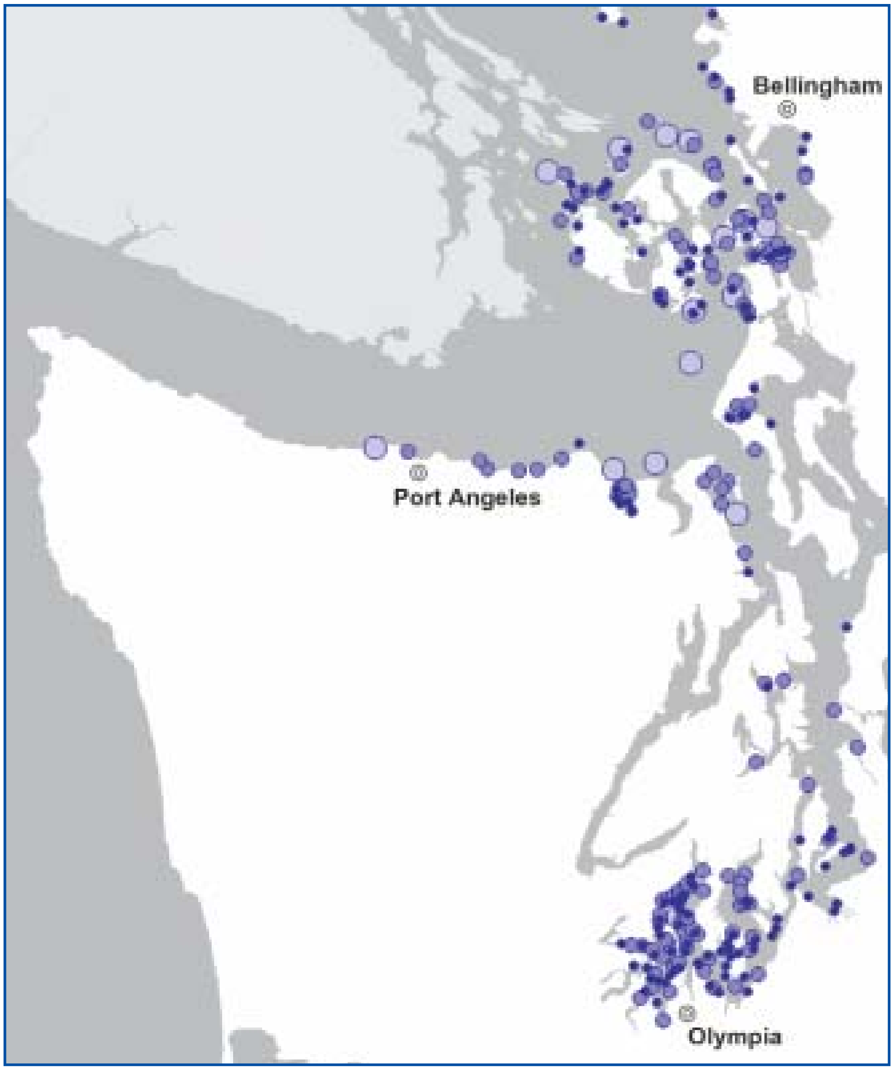
Even though the counts during 2000 were higher than observed in 1999, they should not be considered as an increase to 1999. In 1999 there were far fewer colonies counted, as the coverage was not complete, and there were fewer counts at each colony, leaving a smaller count sample at each colony. The 2000 census should be viewed as the first year of complete coverage of guillemot colonies to be used for future trend analysis.

By continuing this survey that combines standardized timing, methodology, replicates, and geographic coverage within each season, we can better understand pigeon guillemot population trends within the inland marine waters of Washington State.

Figure 6-18. Pigeon Guillemot colonies surveyed in May 1999.

- > 10 Guillemots
- 10 - 99 Guillemots
- >=100 Guillemots

Source: Washington State Department of Fish and Wildlife



Great Blue Heron Surveys—Comparing Aerial and Ground Surveys

A team of regional scientists, with participation of the state Department of Fish and Wildlife, investigated the use of summer foraging grounds by herons. The study focused on the eelgrass bed-associated colonies from Everett north to Boundary Bay. On June 3 and 9, 2001, flights were coordinated with volunteers on the ground counting herons during a minus tide. At this time in northern Puget Sound, herons have large chicks and both adults were expected to be foraging at minus tides. Attendance measures at two colonies confirmed that 95 percent of the nests with chicks were empty, indicating that both adults were out foraging.

The two flights show remarkable similarity and good agreement with the numbers of herons observed by ground observers throughout the low tide (Table 6-7). An additional benefit of this study was the new identification of a colony located on the Lummi peninsula and a potential colony at Portage Island, both on the Lummi Indian Reservation.

Goals for continuation of this work include:

1. Flights on days before and after maximum minus tides to reduce conflicts with shellfish surveys by the state Department of Fish and Wildlife and further focus upon the most efficient time.

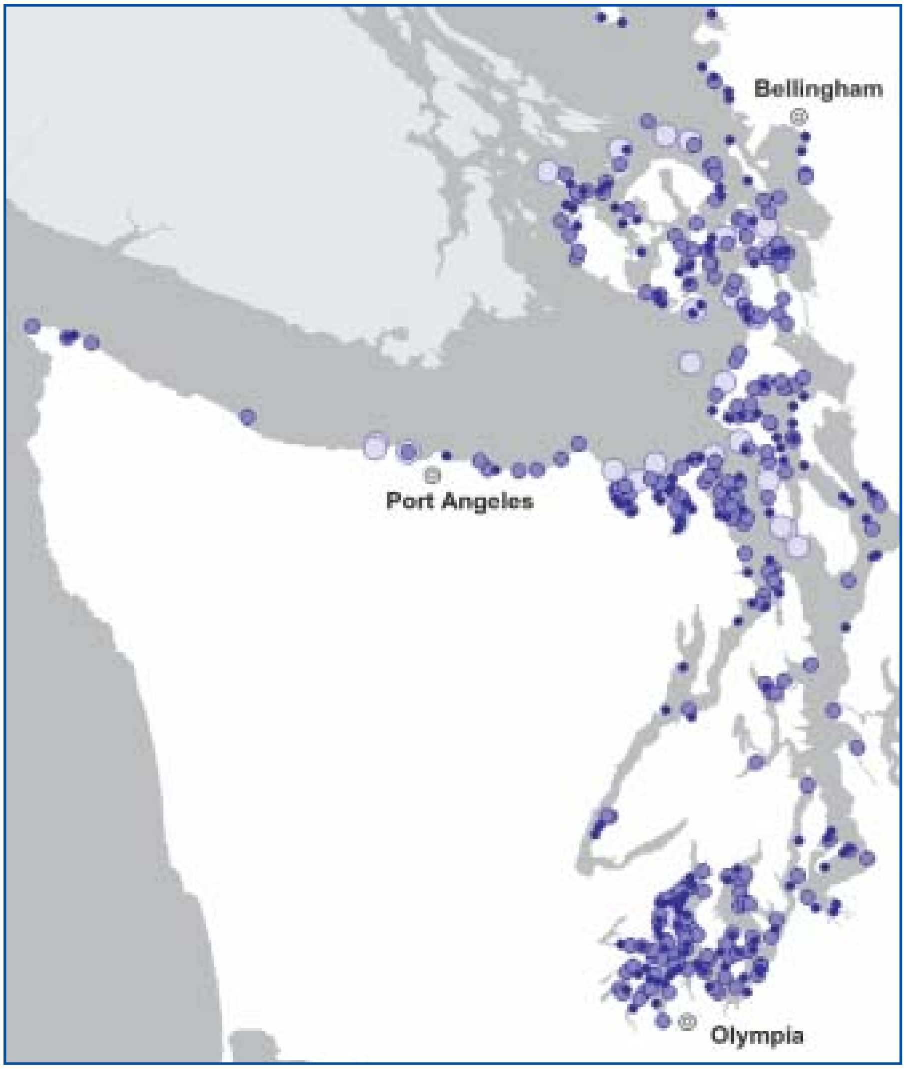


Figure 6-19. Pigeon guillemot colonies surveyed in May 2000.

- > 10 Guillemots
- 10 - 99 Guillemots
- >=100 Guillemots

Source: Washington State Department of Fish and Wildlife

2. Surveys of other locations, especially the outer coast, earlier in the season, to help locate many of the smaller colonies by subsequent arrival and departure monitoring of herons at the foraging areas.
3. Surveys of lakes Washington and Sammamish in King County to locate potential foraging concentrations.
4. Surveys in August to obtain a summer total population count after fledging of chicks.
5. Capturing chicks or adults at some of the King County colonies and marking them to determine if birds from King County are foraging north in eelgrass beds.
6. Ground surveys for juvenile herons in south Port Susan from earlier nesting King County herons.

Hood Canal Bald Eagles

The bald eagle, *Haliaeetus leucocephalus*, ranges over much of North America but has a history of declining populations in the last century, which led to the Bald Eagle Protection Act in 1940 and ultimately to the bald eagle being listing as endangered (in most of the lower 48 states) and threatened (in some northern states including Washington) under the ESA in 1978. Populations have rebounded dramatically during the last 20 years, including in Washington State, leading to a proposal by the

Table 6-6. Summary of May 1999 and 2000 pigeon guillemot counts in the inland marine waters of Washington State. Counts are grouped by whether or not colonies were previously listed in the Catalog of Washington Seabird Colonies.

Source: Washington State Department of Fish and Wildlife

	Listed in Colony Catalog			Not Listed in Colony Catalog			All Colonies	
Year	# of Colonies	# of birds	% of total birds	# of birds	# of Colonies	% of total birds	# of Colonies	# of birds
1999	120	6,740	73%	153	2,432	27%	273	9,172
2000	121	7,840	53%	308	7,012	47%	429	14,852

Table 6-7. Comparison of Great Blue Heron counts from PSAMP aerial surveys and volunteer ground surveys, 2001.

(I) indicates incomplete sampling.

• ground-based count coincident with time of aerial survey

Source: Norman Wildlife Consulting

Region	PSAMP Aerial Survey June 3rd	PSAMP Aerial Survey June 9th	Ground Survey Count	Ground Survey Date
Snohomish River Delta	56	57	60	June 10
Port Susan	110	234	58*	June 3
			74*	June 9
Skagit Bay	124	104	(I)	-
Dugwalla Bay	no data	138	85*	June 3
			114*	June 9
Similk Bay Area	(I)	91	136	June 24
Fidalgo Bay	95	65	55	June 24
Padilla Bay	608	626	390*	June 3
			596*	June 9
Samish Bay	311	259	(I)	June 3
Bellingham Bay	18	1	4	June 9
Portage Bay	38	125	121*	June 9
Lummi Bay	168	75	177*	June 3
			67*	June 9
Birch Bay	38	29	62	June 3
			10	June 9
Drayton Harbor	165	327	236	June 3
			153*	June 9
Boundary Bay	152	137	(I)	June 3
Twassassen Ferry	342	343	315*	June 3
			610	June 24

U.S. Fish and Wildlife Service to remove the bald eagle from the List of Endangered and Threatened Wildlife (USDI 1999). Although the outlook for bald eagles in Washington State is good, the average productivity and success rate of eagles in the Hood Canal area have historically been below the average levels for the state. A new report reviews the population of bald eagles in Hood Canal focusing on toxic contaminant loadings in eagle eggs, blood, tissue and in fish that contribute to the bald eagle diet (Mahaffy et al. 2001).

In 1940, when the Bald Eagle Protection Act was passed, declining numbers were attributed to hunting, loss of nesting habitat and declining number of prey species. Soon after the act was passed, the use of DDT and other organochlorine pesticides became widespread. In the late 1960s and early 1970s, scientists determined that

DDE, the principal breakdown product of DDT, accumulated in the fatty tissues of adult female bald eagles. This impaired eggshell formation, resulting in thin shells and reproductive failure (USDI 1999). In 1972, DDT was banned in the U.S. and in 1986 a bald eagle recovery plan was adopted for the Pacific region, including Washington State. The Pacific recovery plan established goals of an average reproductive rate of 1.0 fledged young per occupied breeding area and an average success rate for occupied breeding areas of not less than 65 percent over a 5-year period (USDI 1999). The plan calls for these population goals to be met in at least 80 percent of management zones.

By 1999, the numeric population goals had been met over the Pacific region as a whole but only in 76 percent of the management zones. On a statewide basis, the Washington bald eagle population is near the recovery goals and fairly stable. The Hood Canal population has been less stable and not as productive as the statewide population (Figure 6-20, Figure 6-21). Nevertheless, the Hood Canal bald eagle population is increasing. This can be seen in the increasing number of occupied territories (Figure 6-22). It is believed that persistent environmental contaminants, especially PCB compounds, are responsible for reduced productivity in the Hood Canal area (see Chapter 4).

Marine Mammals

Petition for Listing of Southern Resident Orcas

In May 2001, the Center for Biological Diversity and 10 other entities petitioned NMFS to list the southern resident community of orcas (*Orcinus orca*), which reside for most of the year in Puget Sound and the Strait of Georgia, as threatened or endangered under the ESA. The population of whales in the three pods that make up the southern resident community declined from 97 to 78 individuals in recent years (Center for Biological Diversity 2001). The petition describes three factors related to this decline: reduced food availability; increased interaction with humans; and high levels of toxic contamination (see Chapter 4 for additional information about PCB contamination in orcas.)

NMFS accepted the petition, conducted a biological review, and announced in July 2002 that ESA listing was not warranted for the southern resident orca population. This decision was based on the fact that the population did not meet criteria contained in the ESA and in a 1996 joint policy document released by the U.S. Fish and Wildlife Service and NMFS. The particular criterion in question is related to the significance of the population to the entire species or subspecies. At this time the scientific community recognizes only one species of orca with no subspecies. This taxonomy is in question among marine mammal specialists, and the NMFS review panel stated that if orca taxonomy is modified, (e.g. if subspecies become recognized) then the question of listing under ESA could be revisited.

The decision was not a refutation of the decline of the population or the prognosis for long-term sustainability. In recognition of their decline, NMFS moved to have the southern resident population declared a “depleted” stock and thereby gain further protections under the Marine Mammal Protection Act (MMPA).

Harbor Seal Population, 1978-1999

In the first half of the 20th century, a state-financed population control program severely reduced the numbers of harbor seals (*Phoca vitulina richardsi*). Bounty hunters severely reduced harbor seal numbers in the early 1900s under a state-financed program that considered harbor seals to be predators in direct competition with commercial and sport fishermen. After the bounty program ceased in 1960 and

King County’s Herons: A Potential Connection to Eelgrass and Salmon

For her master’s thesis research in 2000, Amy Stabins confirmed some 250 successful heron nests at seven King County colonies associated with the Lake Sammamish and Lake Washington system. The colonies at Lake Sammamish State Park, Black River, Redmond Town Center, Kenmore, and Mercer Slough, began incubation almost a month earlier than marine colonies. These five colonies produced 83 percent of the 628 chicks, meaning 900 herons were looking for food in mid to late June. To nest so early requires a food source for the females in February, more than a month before daylight low tides and fish to catch. Groups of herons have been observed foraging at night at the mouth of the Cedar River in February when long-nosed smelt spawn in Lake Washington and possibly also on Lake Sammamish. Nesting at several colonies was earlier in 2001 (Kate Stenberg and Pam Cahn, personal communication). An overlay of the location of the King County colonies also shows an association of herons with locations where large numbers of hatchery sockeye salmon exit streams in April and May, when herons are foraging for their chicks. By June, the outmigrations are over, and food is in short supply—herons likely move to foraging at eelgrass beds. Scientists initiated a closer watch for juvenile birds at Port Susan in 2002.

Figure 6-20. Five-year average number of young bald eagles per nest in Hood Canal and statewide relative to the recovery goal.

- Statewide
- Hood Canal
- Recovery Goal

Source: U.S. Fish and Wildlife Service (Mahaffy et al. 2001)

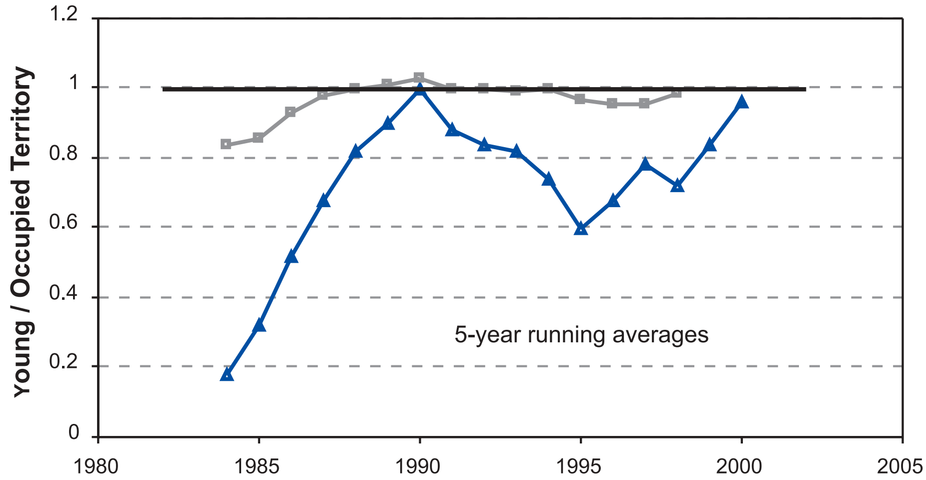


Figure 6-21. Five-year average nesting success of bald eagles in Hood Canal and statewide relative to the recovery goal.

- Statewide
- Hood Canal
- Recovery Goal

Source: U.S. Fish and Wildlife Service (Mahaffy et al. 2001)

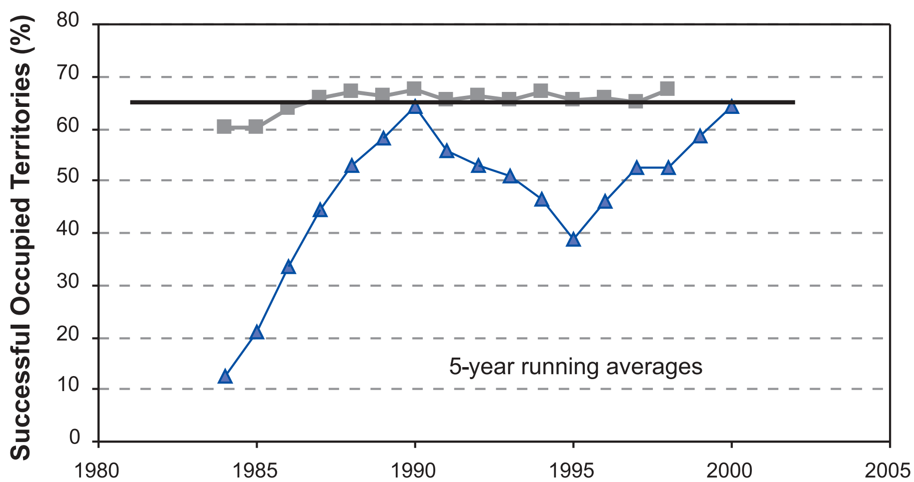
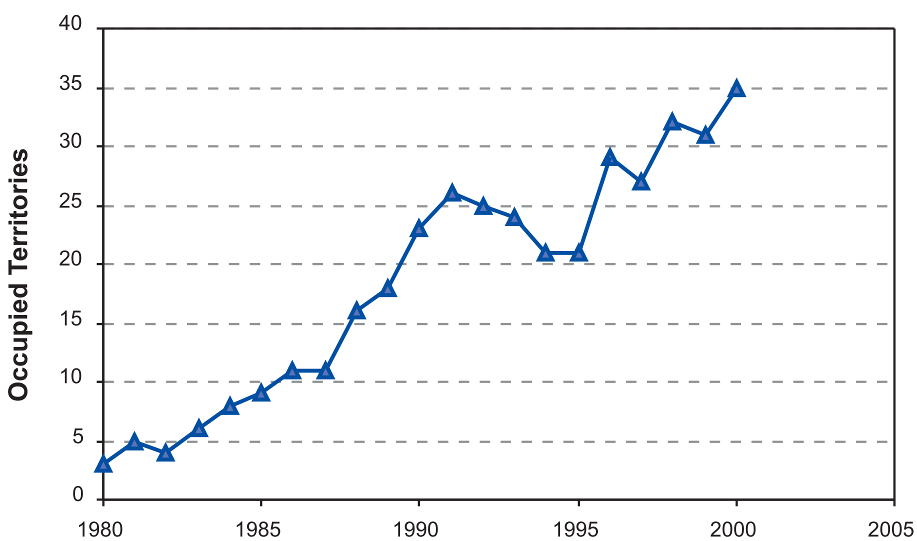


Figure 6-22. Number of occupied bald eagle territories in the Hood Canal area.

Source: U.S. Fish and Wildlife Service (Mahaffy et al. 2001)



the MMPA was passed in 1972, populations of harbor seals in Washington State began to recover. Newby (1973) estimated that 2,000 to 3,000 harbor seals resided in Washington State in the early 1970s.

State and federal scientists collaborated on systematic surveys of Washington's harbor seal population from 1978 to 1999. The aerial surveys of harbor seals reported below took place during the pupping season when maximum numbers were onshore. Since 1994, one of the objectives of the state Department of Fish and Wildlife's PSAMP monitoring efforts has been to continue efforts to monitor harbor seal population trends at haulout sites in Washington's inland waters.

The 22-year time series of systematic surveys of a recovering population provides a unique opportunity to describe population growth of an unharvested marine mammal population.

State Department of Fish and Wildlife scientists used the survey data to develop logistic models that were used to examine population trends and status relative to maximum net productivity level (MNPL), carrying capacity (K) and optimum sustainable population (OSP). The results of this model development are "best fit" parameters for the harbor seal population.

The 1999 count for Washington's inland harbor seal stock corrected for seals in the water during surveys was 14,612 (95 percent confidence interval: 11.154 to 19.140). This value is higher than the observations shown in Figure 6-23 because of the correction for seals in the water.

Survey counts and model results indicate that growth between 1978 and 1999 was not evenly distributed throughout all regions of the state. Between 1978 and 1999, the inland stock grew from 42 percent of the state population to 46 percent. Most growth in the inland stock occurred in the San Juan Islands and the Strait of Juan de Fuca and the least growth occurred in Hood Canal (Table 6-9).

Observed harbor seal abundance has increased three-fold since 1978 and estimated abundance has increased seven to 10 fold since 1970. The logistic growth model fit to the data for the total inland seal population is shown in Figure 6-23. The observed population size for Washington's inland harbor seal stock in 1999 is very close to the predicted carrying capacity (K) for this habitat. Model results also suggest that Washington's inland harbor seal stock is above MNPL. Because there are no records of the number of seals in Washington before exploitation, we don't know whether the present population is larger or smaller than historical levels or if Puget Sound's carrying capacity for harbor seals is different now then in earlier times.

Changes that might have lowered the carrying capacity include decreases in harbor seal prey such as Pacific Whiting (hake) (Gustafason et al. 2000) and herring (Stout et al. 2001a), reduced habitat and increased disturbance.

Harbor Seal Stocks

Harbor seals in Washington and Oregon are separated into coastal and inland stocks because of differences in cranial morphology, pupping phenology, and genetics (Temte 1986; Lamont et al. 1996). The Washington inland stock includes all harbor seals in U.S. waters east of a line extending north-south between Cape Flattery on the Olympic Peninsula and Bonilla Point on Vancouver Island. Interchange between Washington's inland and coastal stocks is unlikely, as no radio-tagged seals from the inland stock have been observed in coastal areas or vice versa.

Aquatic Nuisance Species

The Washington State Exotics Expedition:
A Comparison of Exotic Species in Three Regions

In the spring of 2000, Department of Natural Resources scientists coordinated a rapid survey of exotic organisms to provide baseline information about marine invasions. The cooperative study, called the 2000 Expedition, brought together 22 scientists from diverse institutions to survey exotic species in a broad range of shallow water habitat types. Three regions in Washington State were sampled to compare spatial patterns across a range of oceanographic conditions and patterns of human use:

Table 6-9. Summary of harbor seal surveys for inland stock survey regions in Washington, 1978 to 1999.

Source: Washington State Department of Fish and Wildlife

Survey region	Range of surveys	No of years surveyed	Average no. of surveys/year	Mean counts (percent of population) 1978	1999
Strait of Juan de Fuca	1978-1999	18	1.9	417 (5.7)	1752 (9.0)
San Juan Islands	1978-1999	18	1.3	852 (11.7)	4189 (18.5)
Eastern Bays	1978-1999	17	1.8	755 (10.3)	1873 (9.6)
Puget Sound (south of Admiralty Inlet)	1978-1999	10	2.2	337 (4.6)	1025 (5.3)
Hood Canal	1978-1999	8	1.7	732 (10.0)	711 (3.7)

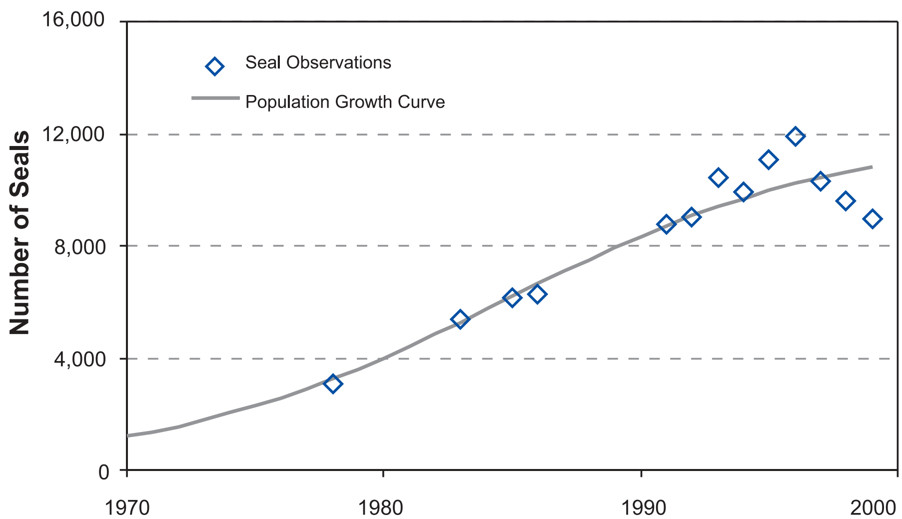


Figure 6-23. Generalized logistic growth curve for inland Washington stock of harbor seals.

Source: Washington State Department of Fish and Wildlife

- **Elliott Bay and the Duwamish River** estuary are located in the central basin of Puget Sound, near the City of Seattle. This is an area of intensive urban development and the site of a major international port, the Port of Seattle.
- **Totten and Eld inlets** are relatively protected bays in the southern basin of Puget Sound. Aquaculture and residential land uses predominate in these inlets. The Port of Olympia, a small international port, is in adjacent Budd Inlet.
- **Willapa Bay** is is a large outer coast estuary. It is the state's largest aquaculture center. Much of its shoreline is undeveloped. There is currently no commercial shipping in the bay.

The 2000 Expedition collected 40 exotic species during seven days of sampling and taxonomic analysis (Table 6-10). Most of the exotic species are native to the North Atlantic or the northwestern Pacific region, and most were introduced to the northeastern Pacific with oysters imported for aquaculture, as ship-fouling organisms or in ballast water. Four of the exotic species collected in Willapa Bay were not previously known from that bay. One of these, the spionid worm *Pseudopolydora bassarginensis*, is a new record for North America. A phyllodocid worm in the genus *Nereiphylla* may be either a new species or a previously unreported introduction. The collection of the native nudibranch, *Emarcusia morroensis*, in Elliott Bay substantially extended its documented range on the Pacific Coast. The terebellid worm *Neoamphitrite figulus*, collected in Willapa Bay during in March 2000, is a new record for the Pacific Coast of North America. (The record is not included among the results of the expedition since it was collected during an earlier reconnaissance survey.)

Among the three regions, 15 exotic species were collected in each of the Elliott Bay and Totten/Eld Inlet regions, and 34 were collected in Willapa Bay. The apparent ecological dominance by exotics was greater in Willapa Bay and slightly greater in Totten and Eld inlets than in Elliott Bay.

Among the three regions, Elliott Bay has experienced the most extensive physical alteration and Willapa Bay the least. Thus the greatest number and extent of invasions was found in the least physically altered system. This pattern appears to contradict the hypothesis that more disturbed habitats are more vulnerable to invasions (e.g. Elton 1958; Lozon and MacIssac 1997). However, it is important to note that while Willapa Bay is relatively undeveloped, it is far from pristine. Habitats and natural processes in the bay have been extensively altered by practices such as diking, agriculture, aquaculture, dredging and deforestation of the watershed. Dominant invaders (Atlantic cordgrass and Japanese oysters) have also altered the physical environment. These results also suggest the possibility that factors other than level of physical alteration play an important role in the level of invasions at these sites (e.g. proximity to other areas rich in exotic species).

Elliott Bay is an important international and coastal shipping center, which Totten/Eld Inlets and Willapa Bay are not. The latter two regions, however, are major historical and current sites for aquaculture. Since these regions appear to be as invaded as (or more invaded than) Elliott Bay, this suggests that aquaculture activities may historically have been as effective as (or more effective than) ship-associated mechanisms in moving organisms across and between oceans, and between bays. Scientists note that aquaculture activities have historically been efficient vectors for moving pests and parasites of shellfish. The shipment and planting of oysters for commercial aquaculture is considered to be a possible mechanism responsible for introducing onto the Pacific Coast 35 of the 40 exotic species collected by the expedition. In contrast, ballast water is considered a possible transport mechanism for 13 of the species, and all ship-associated mechanisms together (ship fouling, solid ballast and ballast water) for 28 of the species. All of these mechanisms would also be effective at moving organisms between bays on the Pacific Coast.

A study of the causes of species introductions throughout North America found the same vectors—aquaculture and shipping—to be the predominant vectors associated with species introductions into marine communities throughout North America (Ruiz et al. 2000). However, the order of importance of the vectors was reversed; shipping was found to be the most important vector for introductions into North America. Beyond the predominance of these two vectors, there remains a great deal of uncertainty about the relative contribution of each mechanism.

Control of Invasive Exotic Spartina

Spartina, commonly know as cordgrass, is a noxious weed that severely disrupts Washington State's native saltwater ecosystems, alters fish, shellfish and bird habitat, and increases the threat of floods. Three species of *Spartina* have been introduced to and have become established in nearshore environments in western Washington.

In Puget Sound, known *Spartina* infestations occur or have occurred at a few locations along the Strait of Juan de Fuca and into Hood Canal, at three locations in San Juan County (one each on San Juan, Orcas and Lopez Islands), in numerous

Table 6-10. Origins, earliest records and mechanisms of introduction of exotic species collected in the 2000 Expedition. Native ranges, dates of earliest record (planting, collection or report) on the Pacific Coast of North America and in Washington State, and possible initial mechanisms of introduction to the Pacific Coast are given. Much of this information is expanded and revised from Carlton (1979), Cohen and Carlton (1995), Cohen et al. (1998) and Mills et al. (2000). Earliest records consisting of written accounts that do not state the date of planting, collection or observation are preceded by the symbol "≤". Mechanisms given in parentheses indicate less likely mechanisms. Mechanisms are listed as:

- SF - in ships' hull fouling or boring
- SB - in solid ballast
- BW - in ships' ballast water or seawater systems
- PM - as packing material for shipped goods
- OA - with shipments of Atlantic oysters
- OJ - with shipments of Japanese oysters
- PL - with shipments of aquatic plants

Source: Washington State Department of Natural Resources

	Native Range	1st Pacific Coast Record	1st Wash. State Record	Mechanism of Introduction
Phaeophyceae				
Sargassum muticum	NW Pacific	1944	1948	OJ
Anthophyta				
Spartina alterniflora	NW Atlantic	ca. 1938	ca. 1938	OA,SB,PM
Zostera japonica	W Pacific	1957	1957	OJ
Porifera				
Clathria prolifera	NW Atlantic	1945-49	≤1967	OA,SF
Cnidaria				
Cordylophora caspia	Black/ Caspian Seas	ca. 1920	ca. 1920	BW,SF
Diadumene lineata	NW Pacific	1906	≤1939	OA,SF
Annelida: Polychaeta				
Hobsonia florida	NW Atlantic	1940	1940	OA,SF,PL
Neanthes succinea	N Atlantic	1896	≈1995	OA,SF
Polydora cornuta	N Atlantic	1932	1937	OA,SF,(BW)
Pseudopolydora bassarginensis	NW Pacific	2000	2000	OJ,SF,BW
Pseudopolydora kempi japonica	NW Pacific	1951	1968	OJ,SF,BW
Streblospio benedicti	N Atlantic	1932	≤1971	BW,OA,(SF)
Mollusca: Gastropoda				
Batillaria attramentaria	NW Pacific	1924	1924	OJ
Crepidula fornicata	NW Atlantic	1905	1905	OA
Ilyanassa obsoleta	NW Atlantic	1907	≤1945	OA
Ocinebrellus inornatus	NW Pacific	1924	1924	OJ
Urosalpinx cinerea	NW Atlantic	1890	≤1929	OA
Mollusca: Bivalvia				
Crassostrea gigas	NW Pacific	1875	1875	OJ
Mya arenaria	NW Atlantic	1874	1884	OA
Neotrapezium liratum	NW Pacific	1924	1924	OJ
Petricolaria pholadiformis	NW Atlantic	1927	≤1943	OA
Venerupis philippinarum	NW Pacific	1924	1924	OJ
Arthropoda: Crustacea: Ostracoda				
Eusarsiella zostericola	NW Atlantic	1953	1998	OA,SF,(BW)
Arthropoda: Crustacea: Cirripedia				
Balanus improvisus	N Atlantic	1853	1955	OA,SF
Arthropoda: Crustacea: Cumacea				
Nippoleucon hinumensis	NW Pacific	1979	1980	BW
Arthropoda: Crustacea: Isopoda				
Limnoria tripunctata	not known	1871 or 1875	1962	SF
Arthropoda: Crustacea: Tanaidacea				
Sinelobus stanfordi	not known	1943	≤1996	SF,BW
Arthropoda: Crustacea: Amphipoda				
Ampithoe valida	NW Atlantic	1941	1966	OA,SF,BW
Caprella mutica	NW Pacific	1973-77	1998	OJ,BW
Corophium acherusicum	N Atlantic	1905	1915	OA,SF
Corophium insidiosum	N Atlantic	1915	1915	OA,SF
Grandidierella japonica	NW Pacific	1966	1977	OJ,SF,BW
Jassa marmorata	NW Atlantic	1938	≤1995	SF,BW
Melita nitida	NW Atlantic	1938	1966	OA,SF,SB,BW
Bryozoa				
Bowerbankia gracilis	NW Atlantic?	≤1923	≤1953	OA,SF
Cryptosula pallasiana	N Atlantic	1943-44	1998	OA,SF
Schizoporella unicornis	NW Pacific	1927	1927	OJ,SF
Urochordata				
Botrylloides violaceus	NW Pacific	1973	1977	OJ,SF
Botryllus schlosseri	NE Atlantic	1944-47	late 1960s-1970s	OA,SF
Molgula manhattensis	NW Atlantic	1949	1998	OA,SF,BW

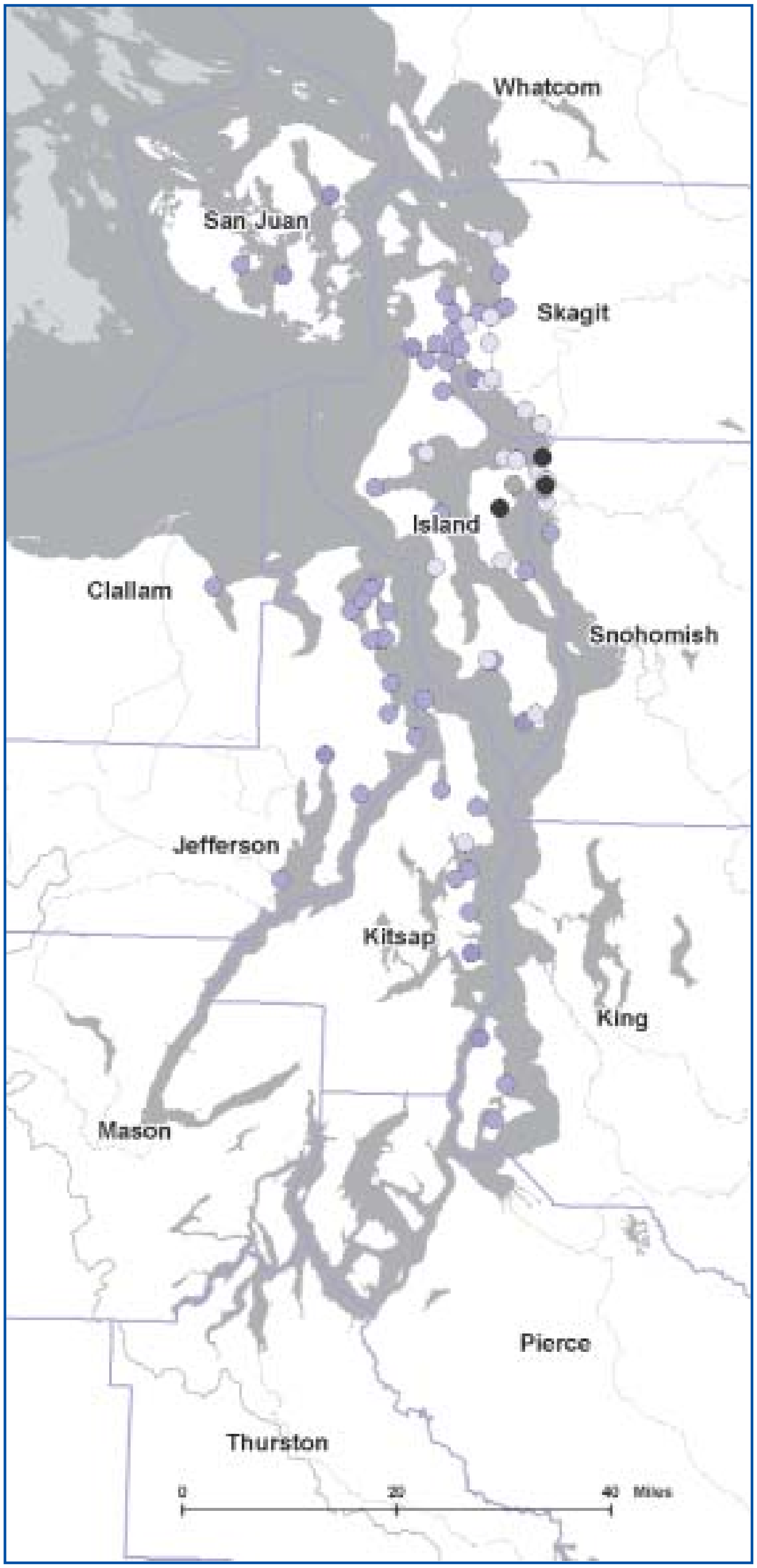


Figure 6-24. Area of *Spartina* infestations around Puget Sound, 2001.

- Removed (2+ years no regrowth)
- <1 solid acre
- 1-5 solid acres
- 6 - 50 solid acres
- >50 acres

Source: Washington State Department of Natural Resources

Green Crab

The European Green Crab *(Carcinus maenas*) is a small shore crab that is native to the Atlantic coasts of the Europe and northern Africa but has been seen in Grays Harbor and Willapa Bay since 1998. The green crab feeds on clams, other crabs, and other invertebrates. The state Department of Fish and Wildlife has an active control program on the outer coast and coordinates a monitoring network across Puget Sound to detect an invasion to the inland marine waters should it occur.

This invasive species presents a major risk to Dungeness crab, clam and oyster fisheries. The green crab may also compete with native fish and bird species for food.

areas along the shorelines of Skagit, Island and Snohomish counties, and at a few locations along the shorelines of King and Kitsap counties (see Figure 6-24). *Spartina* has still not been found south of the Tacoma Narrows in Puget Sound.

The Washington State Department of Agriculture coordinates a *Spartina* eradication and control program. As part of this program, the department conducts all control work in San Juan, Clallam, Jefferson, Kitsap and King counties and also coordinates the entire Puget Sound/Hood Canal Effort. The agency allocates funding and other support to Island, Snohomish and Skagit counties, private landowners and the Swinomish and Suquamish tribal communities. In addition, state Department of Fish and Wildlife staff conduct substantial control work on their property throughout northern Puget Sound and assist county control efforts as time and funding permit.

As of the beginning of the 2001 control season, the control efforts of the Department of Agriculture and its partners have resulted in significant progress in reducing the size of the Puget Sound *Spartina* infestation (and in a few cases eradicating them). As the Department of Agriculture and collaborators such as the state Department of Fish and Wildlife succeed at reducing or eliminating smaller, outlying populations of *Spartina* that have the potential to greatly increase in area, larger areas of infestations, such as south Skagit Bay, will become a bigger priority and the focus of additional funding.

The 2001 Washington State legislature appropriated more funds to the Department of Agriculture for the control of *Spartina* . With this enhanced level of funding Agriculture and its cooperators will be able to eradicate all known *Spartina* infestations in Puget Sound and Hood Canal in four years.

Acting on the Findings

The studies presented in this chapter affirm the importance of continued monitoring and the development of new monitoring studies when plant and animal populations change noticeably for unknown reasons.

Studies such as those presented here provided strong evidence supporting the strategy of basing resource management decisions on sound science. The best example lies in earlier studies that linked bald eagle decline with persistent toxic contaminants and ultimately led to the banning of these contaminants. Results of continued monitoring discussed in this chapter have affirmed this strategy by showing a decline of contaminant levels and recovery of the eagle.

The results from these monitoring studies have also led to direct management actions, especially in developing conservative harvest guidelines for groundfish and the consideration for a network of marine reserves for rockfishes and other species.

Some specific recommendations follow directly from the results of studies presented in this chapter:

- Monitoring designed to understand dynamics of stocks or populations should include organisms at a range of trophic levels in addition to the species of interest. Results have shown the importance of considering food web interactions in understanding a population in addition to direct relationships with the physical environment.
- Scientists and resource managers need to increase their focus on efforts to understand the causes underlying declining populations

where management actions have not brought expected improvements, such as with specific groundfish species.

- Scientists need to explore new techniques that may increase the scope of monitoring studies with limited funding resources. Examples include the use of remote sensing platforms (aircraft, satellite) to replace or augment ground surveys and automated instrumentation to replace manual data collection wherever possible.
- Wherever appropriate and feasible, multi-disciplinary monitoring should be employed such as coupling population surveys with collection of toxic contaminant or physical environmental data.
- Scientists need to focus on the detection of ecosystem-level changes, e.g. changes in the structure of food webs, that may not be obvious from a species or population perspective but may be fundamentally more significant.
- Since its release in 2000, The ShoreZone Inventory has been widely used by scientists and planners. More than 1,000 copies of the digital data have been distributed in response to data requests. Datasets like the ShoreZone Inventory can be used to improve resource management and land use planning. However, additional funding is needed for data distribution and support. Too often, funds are not provided because the importance of these tasks is not recognized. There is also a need for dedicated mechanisms to fund updating datasets and integrating feedback from users.
- Results presented in this chapter underscore the need for consistent long-term data on biologically relevant environmental variables that scientists can use to interpret changes in key biological populations. This type of data and subsequent analysis will be needed to help increase understanding of the influences of human-caused environmental stressors and corrective actions.